

Lowell Canal System  
Lowell, Massachusetts  
Middlesex County

HAER No. MA-1

HAER  
MASS.  
9-LOW,  
8-

REDUCED COPIES OF MEASURED DRAWINGS  
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Historic American Engineering Record  
National Park Service  
Department of the Interior  
Washington, D.C. 20240

HISTORIC AMERICAN ENGINEERING RECORD  
LOWELL CANAL SYSTEM

HAER  
MASS,  
9-LOW  
8-

DATE: 1796 and 1821, with later additions and alterations

LOCATION: South of the confluence of the Merrimack and Concord Rivers, Middlesex County, Massachusetts

DESIGNED BY: Laommi Baldwin, Patrick Tracy Jackson, James Francis, and others

OWNER: Proprietors of the Locks and Canals on the Merrimack River

SIGNIFICANCE: The City of Lowell is generally considered to be the birthplace of large-scale manufacturing in the U. S. Begun as a transportation canal, the Lowell Canal System evolved, during the 19th century, into one of America's foremost water power sites. Pages 2 to 125 of the attached reports provide a detailed history of the early canal system and the city; pages 126 to 150 comprise a briefer summary of Lowell's engineering and industrial developments during the 19th century.

HISTORIAN: Patrick M. Malone, 1975

TRANSMITTED BY: Monica E. Hawley, Historian ,1983

## CHAPTER I

The Merrimack River flows down from the highlands of New Hampshire, past the great industrial cities of Manchester, Lowell, and Lawrence, and into the sea at Newburyport, on the northern coast of Massachusetts. The natural drainage basin of the river extends northward to the shadows of Mount Washington. Near that peak are the headwaters of the Pemigewasset River. Streams and lakes feed the Pemigewasset, as it runs south to Franklin, New Hampshire. There, the Winnepesaukee River joins it from the northeast, bringing the full discharge of Lake Winnepesaukee and its southern bays. The junction of these two rivers forms the Merrimack at Franklin, two hundred and sixty-nine vertical feet above the mean tide at Newburyport.<sup>1</sup>

In its one hundred and ten mile journey to the sea, the Merrimack does not give up its altitude in a smooth, uniform descent, but instead, drops forcefully over a number of falls, rapids, and manmade dams. One of the greatest changes in the level of the river occurs at Pawtucket Falls, just south of the New Hampshire line in Lowell. For centuries, these falls produced a natural descent of more than thirty feet, "not perpendicular, but over several rapids, in circuitous channels, with a violent current amidst sharp-pointed rocks."<sup>2</sup> A masonry dam now stands at the head of the falls, diverting much of the water into power canals, but also increasing the drop through the rugged stone

formations which stretch for almost a mile downstream.

The river makes a turn to the northeast before entering Lowell, then bends sharply to the southeast, after passing the rapids of Pawtucket Falls. It continues in that direction for a mile, before the Concord River joins it from the south. Then, the Merrimack swings again to the northeast and the sea, some thirty-seven miles away. The great falls, the bend, and the confluence of two rivers in Lowell have made a major impact on the history of the area.

Pawtucket Falls and the smaller falls on the final two miles of the Concord were essential fishing spots for bands of Indians from the Algonquian language group. Salmon, shad, and alewives traveled up the Merrimack to spawn and could be taken in vast numbers at the major falls and rapids. Long before the coming of the white man, Indians gathered in the spring to fish with net, spear, and arrow. The Puritan missionary, John Eliot, preached to the Indians in the "praying town" of Wamesit, within the present boundary of Lowell. Later, colonists took an active interest in the fisheries, the arable land, and the "unimproved" water power of the area. By 1685, the Indians of Wamesit had sold their lands, and the area was considered an eastern section of the town of Chelmsford.<sup>3</sup>

Harnessing the full power of the major falls on the Merrimack or Concord was too ambitious for the early settlers of East

Chelmsford, but a number of small mills in the area used falling or rushing water to power their operations, before the end of the eighteenth century. In 1691, John Barret had a "clothier's mill" on River Meadow Brook, which flows into the rapids of the lower Concord. Another mill lot, laid out beside the brook in 1696, was the site of a saw mill by 1714. A "Plan of Chelmsford", drawn in 1794, shows the clothier's mill, with a saw mill and grist mill nearby. An ironworks and two saw mills appear on the lower Concord and a saw mill and grist mill below Pawtucket Falls on the Merrimack. The plan also shows another saw mill near the head of the falls. One sawyer had an earlier mill beside Pawtucket Falls, but the great freshet of 1785 swept it away.<sup>4</sup>

For many of the early settlers of the Merrimack Valley, the major falls of the river were more of an economic obstacle than an opportunity. The loggers and producers of forest products were particularly distressed by the liabilities of the river as an artery of commerce. Rafts of logs could float over small falls or rapids in high water, but teams of oxen had to haul the logs around Pawtucket Falls.<sup>5</sup> If the falls could be bypassed by a canal and minor improvements made at other rough sections of the river, northern products could be transported to the coast with much less difficulty.

In 1792, a group of merchants from Newburyport formed a company to build a canal around the falls. They hoped that tolls on the canal would bring them a sizeable profit and that their city

would prosper from the expected increase in river traffic. The demand in Newburyport for masts, lumber, naval stores, and other products from the New Hampshire forests seemed to guarantee the success of a transportation canal in East Chelmsford. The new company, incorporated as the Proprietors of the Locks and Canals on Merrimack River, made rapid plans for canal construction.<sup>6</sup>

The directors met on the site in August 1792, and chose a rough route for the canal. It was to begin just above Pawtucket Falls, "near the great landing place, thence running to Lily Pond, from thence, by Speen's Brook to Concord-River." This path kept excavation to a minimum and capitalized on an existing pond and stream to create a navigable waterway. However, the engineering problems were still difficult, and locks would be needed to take boats and large rafts through the changes in elevation between the upper Merrimack and the lower Concord. From the proposed end of the canal in the Concord, rafts could float a few hundred yards into the Merrimack.

Work on the project commenced with "measures to clear the bushes" and to make an "accurate survey." The first president, Jonathan Jackson, and the six other directors of the company, hired men to begin excavations, in the fall of 1792. However, by January, they had decided to contract for "the digging of the canal around Pawtucket Falls to a sufficient depth for receiving the Locks and of the width of forty feet." Of the proposals

submitted to the directors, they finally chose that of one of their own members, Joseph Tyler. In March 1793, he received the contract with detailed specifications of his task.<sup>8</sup>

The directors gave Tyler some choice in picking "the best and most convenient route" from the chosen entrance of the canal to Lily Pond, but he was to stay with Speen's Brook thereafter. The method of construction, exclusive of locks and bridges, was left vague. According to the contract, the canal would operate around the falls, whenever the rest of the Merrimack was passable. The manmade waterway had to be large enough to handle "rafts, masts, and floats of timber, not exceeding thirty feet width and one hundred feet in length." It also had to carry boats of no more than three foot draft, either up or downstream.<sup>9</sup>

The number of locks in the canal was not specified, although their structure was:

He will make, erect, and finish a suitable and convenient number of Locks in a good, substantial, and workmanlike manner, in manner & form and according to the dimensions and particulars following, that is to say. - The said Locks shall not be less than thirty-two feet in width from inside to inside, and shall be so constructed as that the water shall flow from the lower gate of each to the upper gate of the same, measuring and including not less than three hundred Feet in length, from every such lower Gate to every such upper gate of each Lock; The Floor-Timbers of the Locks shall be sufficiently large and strong, and not more than five feet distant from each other measuring from center to center on an average of the whole number of the said floor-timbers; the posts shall be not less than twelve inches by sixteen inches square clear of sap. The planks shall be not less than

two inches & an half thick, and so much of the said plank as shall be subject to be alternatively wet and dry shall be clear of sap: The caps and braces shall be not less than twelve Inches by fourteen inches square clear of sap; All the Timbers shall be of that species of white pine commonly called corky pine, or of other wood equally good and suitable for that purpose, and there shall not be less than one hundred and fifty feet distance any two gates of a Lock.<sup>10</sup>

The contract also required Tyler to build necessary bridges and to provide a towpath beside the canal. He was to finish all of his construction "in a thorough and workmanlike manner" by June 25, 1795. After completion of the canal, he was still responsible for the repair and maintenance of "the said Canal, Locks, Bridges, and Towing-Path and every part thereof for the term of ten years." He was not liable for damage caused by "the immediate act of Almighty God," neglect by company employees, or proven vandalism.<sup>11</sup>

The canal excavation went well for a year, but the time and costs of cutting or blasting through stone ledges proved greater than expected. Labor charges rose rapidly, and the Proprietors had to advance large sums of money to Mr. Tyler, in order to continue the project. In September 1795, an inspection of the unfinished canal revealed the need for more excavation over major parts of the route and modifications to deepen the final section of the "lower lock" (or set of locks). Only two locks were mentioned, at that time: an "upper lock", thirty-two feet by three hundred feet in plan; and a "lower lock", thirty-two feet

by three hundred feet. It is probable that the "lower lock" contained more than one lock chamber. Both the upper and lower were made of wood.<sup>12</sup>

In January 1796 Mr. Tyler became seriously ill. The Proprietors then gave supervision of the canal project to Thomas Clark, and with the permission of the Massachusetts legislature, the time for completion of the canal was extended. Finally, in the fall of 1796, the 9,188 foot canal seemed ready for an official opening. The directors' records mention only one "disagreeable incident" on opening day, which prevented passage of the canal for several weeks.<sup>13</sup> Wilkes Allen, an early historian of Chelmsford, provides more detail on this minor disaster of October 18, 1796:

The occasion had called together a great concourse from the vicinity. When a novel, and very distressing spectacle was exhibited - some hundreds of men, women, and children were collected, and stood around and upon the locks to witness the passing of a boat, in which were the Directors and other Gentlemen, invited by them to take a trip through the Locks. Scarcely had they entered the first Lock, when the sides suddenly gave way. The water, bursting upon the spectators with great violence, carried many down the stream. Infants were separated from their mothers, children from their parents, wives from their husbands, young ladies from their gallants, and men, women, timber, and broken boards and planks were seen promiscuously floating in the water. Some had their clothes partially torn off, others entirely(sic). Mothers were shrieking for their lost children, husbands swimming in search of their wives and daughters; paleness sat on the countenance and anxiety filled the hearts of those on shore, for the safety of their friends in the water. All, at

length, came safely to land without any material injury. Thus ended the amusement of that memorable day.<sup>14</sup>

Despite rapid reconstruction of the broken lock chamber, low water and the early arrival of winter delayed the commercial use of the canal until the following spring. Costs had risen so high, by 1797, that the Proprietors petitioned the state legislature for higher rates of toll than were originally authorized in 1793. They argued that the canal had cost more than twice what they had planned to spend.<sup>15</sup> The following extensive list of tolls was passed on 17 June 1797, but most of the canal traffic, from its opening to the present time, was rafts of timber.

For every thousand feet pine boards fifty cents- For every thousand feet two inch pine plank, one dollar, for every thousand feet three inch pine plank, one dollar & fifty cents, for every thousand feet oak boards, one dollar, for every thousand feet two inch oak plank two dollars, for every thousand feet three inch oak plank, three dollars; for every thousand shingles, six & one-quarter cents, for every thousand clapboard, thirty-three & one-third cents; for every ton of ash & all other timber except pine & oak, twenty-five cents; for every ton of stone, twenty-five cents; for every thousand hogshead, hoop poles, eight-seven & a half cents, for every thousand hogshead hoops, fifty cents; for every thousand barrel hoop poles, sixty-two & a half cents; for every thousand barrel hoops, thirty-three & one-third cents, for every barrel pot & pearl ashes, ten cents, for every barrel tar pitch, turpentine, cyder, perry, beef, pork or other merchandise not herein aftermentioned; six & one quarter cents; for every dozen kegs lamp black, two & one-half cents; for every hogshead filled with heading or other mechandise, seventeen cents; for every empty hogshead, four and a half cents; for every empty barrel or shaken hogshead, one and a half cent, for every hundred-weight of hay,

flax, hemp, hops, beef, pork salted & other meats, two and an half cents; for every bushel wheat, rye, Indian corn flour, flaxseed, oats, barley, peas, beans, beets, buckwheat, onions, potatoes, parsnips, carrots, apples, or pears, one and a half cent; for every dozen sheep or swine, seventeen cents; for every dozen turkeys or gees, six and one-quarter cents; for every dozen other fowls, two cents.<sup>16</sup>

Even with the higher tolls, the canal's cost of construction made it impossible for stockholders to turn a quick profit. By 9 October 1797, when Mr. Clark was paid in full, costs directly attributable to construction totalled \$32,934. Approximately \$40,000 had been spent on the project, as a whole, yet the tolls, received by 30 September 1797, amounted to only \$1,683.56. Ice closed the canal each winter, and the river trade was heavy only during high water, when the raft men could run the lesser falls. The canal would also cost further money, if the proprietors wanted it to remain serviceable.

The canal had to be deepened and locks built or repaired several times, in the decade following the opening. In 1798, the "guard locks," below the entrance of the canal, are mentioned in the records. A freshet, that year, damaged the canal above this lock ("locks" often meant a single lock chamber, in this period), and laborers used timber to shore up the banks. Efforts to secure permission for a dam at Pawtucket Falls were unsuccessful in 1801, so the problem of shallow water in the ledge section of the canal forced further excavation and, apparently, the construction of another lock. The Proprietors ordered "three of the locks" rebuilt

in 1803, because of decay, but bought timber "sufficient for building four locks."<sup>18</sup>

A map drawn in 1821, after further repairs and alterations, shows the transportation waterway, known by then as the Pawtucket Canal, with three single locks and one flight of three locks in a row. The last set, called the "Lower Locks," took rafts and boats in three steps between the final level of the canal and the lower level of the Concord River. The single locks above were the "Guard Locks," which protected the canal from floods on the Merrimack; the "Minx Locks", which helped maintain an adequate water level across the ledge section; and the "Swamp Locks", set in a marshy area and originally called the "Upper Locks."<sup>19</sup> The locks were wooden, and probably about twenty-seven feet wide, since their reconstruction earlier in the century.<sup>20</sup>

In addition to working on their own canal, the Proprietors of Locks and Canals were obligated by charter to improve navigation on the Merrimack River, from the New Hampshire border to tidewater. This was a big order for the struggling company, but they did try to make the river passable part of the year, at least for rafts. They concentrated most of their on Hunt's Falls, just below the junction of the Concord and Merrimack. In 1799, the Proprietors paid James Varnum for "expenditures to render the falls in Merrimack River below those of Patucket (sic) passable with boats and rafts."<sup>21</sup> This was one of many attempts to cut channels and bypass rapids, but

the Merrimack remained a challenge to river traffic, throughout the nineteenth century.

J. W. Meader, historian of the Merrimack, tells the story of an accident at Hunt's Falls, in the formative years of Lowell.

A fisherman took a great haul of shad from the lower Concord ...

A large raft was then constructed and boarded up, several feet high at the sides, and the shad were placed in it and shipped for Newburyport; but, alas, for human calculations! The raft grounded on an obtrusive boulder, while running Hunt's Falls, and each individual item of the large cargo returned to its native element.<sup>22</sup>

One group of investors saw a way to avoid the obstructions in the river, from Pawtucket Falls to the sea. In 1793, when the Proprietors of Locks and Canals had just begun excavation for the Pawtucket Canal, another company acquired a charter, authorizing the construction of a canal from the Merrimack River to the Mystic River, near Boston Harbor. "The Proprietors of the Middlesex Canal" planned to construct the longest canal up to that time in the United States, and with it, to make Boston the market for most of the Merrimack River trade. By connecting Boston with a water route from the upper Merrimack, they would, as a consequence, direct enough traffic from the Pawtucket Canal to cause the Proprietors of Locks and Canals serious financial difficulty.

With the turning of the first sod for the Middlesex Canal, in 1794, the future of the Pawtucket Canal was in jeopardy. In November of that year, Jonathan Jackson wrote letters for the

Proprietors of Locks and Canals, in which he urged some form of opposition to the competing venture. Addressing his letters to friends of the older canal company, he warned that "A canal is now in actual execution, intended by its proprietors to turn the trade of our River, from its old and natural channel, to the waters of Boston Harbour."<sup>24</sup>

The construction of the Middlesex Canal was a difficult and lengthy process. Colonel Laommi Baldwin of Woburn, Massachusetts, took charge of the project soon after its inception, but admitted his lack of training, in a letter in October 1794.

Having had the honor of being appointed Superintendent of the Middlesex Canal, it remains for me to give my answer on that appointment: The first thing that presents in considering the question is ability to Execute the design in a proper manner, on this, I certainly have nothing to boast, having had no Experience at all. It is true I have studied the theory for many years, and have been at considerable pains to get possessed of the principles of Canaling, but I have never yet seen one foot of Canal which has been compleated in a proper and the most approved manner, this I say, upon the strength of what I have read on the subject and Mr. Weston's information.<sup>25</sup>

Mr. Weston was an experienced English engineer, who gave invaluable advice and assistance to Colonel Baldwin. He lent Baldwin his leveling instrument, which made accurate surveying possible, and with which Baldwin proved the errors in a 1793 survey by a local magistrate. Weston came to Massachusetts for six weeks, in the summer of 1794, in order to take levels, instruct Baldwin in surveying techniques, and make recommendations for possible canal

routes. In later years, he gave advice by letter, providing Baldwin with technical information about lock design and other structural problems.<sup>26</sup>

In its final form, the Middlesex Canal was an amazing engineering achievement. Completed in 1803, it stretched beyond its original destination on the Mystic River, to terminate directly in Boston Harbour at Charleston. It was twenty-seven miles long, with twenty locks and eight aqueducts.

At Middlesex Village, several miles upstream from the Pawtucket Canal entrance, a flight of three stone locks demonstrated the influence of Weston's English conception of engineering permanence. Although rising costs eventually forced Baldwin to switch to wooden lock construction, his first locks of stone, set in a form of hydraulic cement, were far superior to anything on the smaller canal in East Chelmsford.<sup>27</sup>

The owners of the Middlesex Canal encouraged, and often paid for, major navigational improvements on the upper Merrimack. This increased the use of their primary canal and allowed them to collect some tolls from raftmen going further down river through the Pawtucket Canal. Eventually, locks and small, bypassing canals took boats, rafts, and masts around all the troublesome falls between Concord, New Hampshire, and the Middlesex Canal.<sup>28</sup> As passengers and freight traveled back and forth on the Middlesex, the Proprietors of Locks and Canals counted the meager returns on their Pawtucket investment.

The Proprietors of Locks and Canals received their first dividend of one dollar per share in 1798. By 1821, they had collected some small return almost every year; although, on one occasion, the company had to borrow money to make dividend payments. Even with several toll increases, the annual return on each of the six hundred shares of stock averaged three and one half percent. Assessments brought the cost of each of the six hundred shares of stock to about one hundred dollars by 1821, and the owners could only foresee more expenses without substantial increases in dividends.<sup>29</sup>

Although the Pawtucket Canal was not yet a total failure in 1821, most of its proprietors were in the mood to sell their stock, if they could find an eager buyer. Few people seemed optimistic about the future prospects of the old transportation canal. However, a group of industrialists were looking for a suitable site to build a textile manufacturing community, and they needed a great source of water power - such as Pawtucket Falls. In the autumn of 1821, East Chelmsford suddenly became a very important place.

FOOTNOTES CHAPTER I

- [1] See J. W. Meader, The Merrimack River; Its Source and its Tributaries (Boston, 1869), pp. 40, 46-47; and Dwight Porter, "Water Power of the Merrimac River and of the Rivers of Eastern Massachusetts Between the Merrimac and the Blackstone" (unpublished study in possession of Locks and Canals, 1899), pp. 7-8, 11a.
- [2] Henry A. Miles, Lowell As It Was, and As It Is (Lowell, 1845), p. 14.
- [3] See Meader, The Merrimack River, pp. 242-44, 248, 258-59, 282-83; Henry S. Perham, "The Wamesit Purchase," CORHA, IV, 125-44.
- [4] See, Meader, The Merrimack River, p. 246-47; Perham, "The Wamesit Purchase," pp. 135-36; Z. E. Stone, "Before the Power Loom: The Earliest Cotton and Woolen Industries at East Chelmsford and Vicinity and Their Promoters," CORHA, IV, 48-50; and Frederick French, "A Plan of Chelmsford" (Massachusetts Archives, 1794).
- [5] Meader, The Merrimack River, p. 247.
- [6] See Locks and Canals, Charter of 1792, in Directors' Records; Wilkes Allen, The History of Chelmsford (Haverhill, Massachusetts, 1820), p. 69; and for the history of the early company, Nancy Melia, "The Proprietors of the Locks and Canals on the Merrimack River, 1792-1825," M. A. Thesis, Boston College, 1967.
- [7] See Locks and Canals, Directors' Records, 23 August 1792; and "Speen's Brook," plan of East Chelmsford dated 25 May 1792 (Massachusetts Archive, Maps and Plans #994).

- [8] Locks and Canals, Directors' Records, 23 August 1792, 10 January 1793,  
and 16 May 1793.
- [9] Ibid., 16 March 1793.
- [10] Ibid.
- [11] Ibid.
- [12] Ibid., 11 September 1795.
- [13] Ibid., 14 September 1795, 16 December 1795, and 27 January 1796.
- [14] Allen, History of Chelmsford, p. 70.
- [15] Locks and Canals, Directors' Records, 16 December 1796, and 22 May  
1797.
- [16] Ibid., 22 June 1797.
- [17] See expenditures and toll collections in Ibid., 1792-97.
- [18] Ibid., 12 September 1798, 6 January 1801, 21 July 1802,  
14 September 1803, 8 December 1803, and 26 December 1803.
- [19] Locks and Canals, Jonathan Hale, "A Plan of Sundry Farms etc. at  
Patucket in the Town of Chelmsford" (copy of 1821 map).

[20] Locks and Canals, Directors' Records, 21 July 1802.

[21] Ibid., Charter of 1792, 14 June 1793, and 13 March 1799.

[22] Meader, The Merrimack River, p. 282.

[23] Christopher Roberts, The Middlesex Canal, 1793-1860 (Cambridge, 1938)  
p. 29.

[24] Locks and Canals, Directors' Records, 11 November 1794.

[25] Baldwin, quoted in Roberts, The Middlesex Canal, pp. 40-41.

[26] Ibid., pp. 46-48, 53-58, 101.

[27] See Ibid., pp. 101, 191-96; Middlesex Canal Mss., L. Baldwin to  
Joseph Banks, 16 June 1796; and "The Middlesex Canal," a pamphlet with  
a map (Middlesex Canal Association, Billerica, Massachusetts.)

[28] See General George Stark, "Navigation of the Merrimack River," CORHA  
III, 291-293; and Lorin Dame, "The Middlesex Canal," CORHA, III, 279.

[29] See Locks and Canals, Directors' Records, 1798-1821; Nathan Appleton,  
Introduction of the Power Loom, and Origin at Lowell (Lowell, 1858), p. 23,  
and Melia, "The Proprietors of the Locks and Canals," p. 44.

## CHAPTER II

Industrialists, searching for a new manufacturing site, in 1821, were connected with the highly successful Boston Manufacturing Company of Waltham, Massachusetts. The company was founded in 1813, by Francis Cabot Lowell, a Boston merchant, who had visited England and returned with new ideas about textile machinery and the factory system. With the aid of close business associates Patrick Tracy Jackson and Nathan Appleton, and the assistance of Paul Moody, a skilled machinist, Lowell rapidly put his ideas into practice. He and Moody developed a workable form of the power loom, at the same time that such machines were gaining acceptance in England. Then, for the first time anywhere, Lowell combined all the processes of cotton cloth manufacture in a single mill at Waltham. Raw cotton entered the mill, and as a result of mechanical operations driven by water power, emerged as cloth.<sup>1</sup>

At the time of his death in 1817, Lowell's Waltham operations were famous, not only for their technological sophistication and steady profits, but also for an unusual type of corporate paternalism. Most of the labor force was made up of female factory operators, who lived in well-supervised company boarding houses near the mills. Many were New England farm girls, lured by good salaries and the promise of a comfortable and secure lifestyle. Lowell never intended for his female works to become a permanent proletariat; he expected

that, after a few years of factory labor in a proper social environment, they would return to their homes improved by the experience. His "Waltham system" attracted an ample supply of workers, in an area where labor was often scarce, and gave him a reputation as both a social reformer and an effective businessman.<sup>2</sup>

Patrick Tracy Jackson, who had managed the Waltham Mills for Lowell, and Nathan Appleton, a major shareholder and prominent merchant, wanted to expand textile operations, but the Charles River, at Waltham, provided insufficient water power for their plans. In 1821, they decided to find a new location, where they could make and print calicoes, a form of cloth not yet produced in the United States. This plan would require land, new factories, a print works, corporate housing, and a great amount of water power. Jackson and Appleton knew that the plain cloth made in Waltham had a reliable market, yet they dreamed of much greater and more varied production, in an entire community created for textile manufacture.<sup>3</sup>

Appleton, in his Introduction of the Power Loom, and Origin of Lowell, gives the impression that he and Jackson had some difficulty locating a site with adequate water power for a large manufacturing enterprise. They looked at a fall on the Souhegan River near the Merrimack, and went right by the Nashua River, without noticing the fall there.

Soon after our return, I was at Waltham, one day, when I was informed that Mr. Moody had lately been at Salisbury, when Mr. Ezra Worthen, his former partner, said to him, "I hear Messrs. Jackson and Appleton are looking out for water power. Why don't they buy up the Pawtucket Canal? That would give them the thirty feet." On the strength of this, Mr. Moody returned to Waltham by that route, and was satisfied of the extent of the power which might be thus obtained, and that Mr. Jackson was making inquiries on the subject. Mr. Jackson soon after called on me, and informed me that he had had a correspondence with Mr. Thomas M. Clark, of Newburyport, the Agent of the Pawtucket Canal Company, and the lands, necessary for using the water power, could be purchased at a reasonable rate, and asked me what I thought of taking hold of it. He stated that his engagement at Waltham would not permit him to take the management of a new company, but he mentioned Mr. Kirk Boott as having expressed a wish to take the management of an active manufacturing concern, and that he had confidence in his possessing the proper talent for it. After a consultation, it was agreed that he should consult Mr. Boott, and that if he would join us, we would go on with it. He went, at once, to see Mr. Boott, and soon returned to inform me that he entered heartily into the project; and we immediately set about making the purchases.<sup>4</sup>

Appleton and Jackson could hardly have been unaware of the potential of Pawtucket Falls or the financial plight of the Proprietors of Locks and Canals. Jonathan Jackson, the first president of the old canal company, was, after all, the father of Patrick Tracy Jackson. The mercantile community of Boston and Newburyport certainly knew of the Pawtucket and Middlesex Canals. Kirk Boott, a former British Army officer from a New England family, had even hunted in East Chelmsford, before becoming involved with Jackson's plans.<sup>5</sup>

Although Jackson may have played a bigger role in site selection and initial financial investment than Appleton records, both men soon

agreed on a scheme for the secret purchase of stock in the Proprietors of Locks and Canals, and of land in the area. Kirk Boott took charge of the acquisition program, using Thomas Clark, the agent of the Pawtucket Canal, to make most of the actual purchases. Appleton explains that Clark took "the deeds in his own name, in order to prevent the project taking wind prematurely."<sup>7</sup>

With land and stock transactions underway, the men behind the grand plan traveled to the site. Nathan Appleton writes of their inspection:

Our first visit to the spot was in the month of November, 1821, and a slight snow covered the ground. The party consisted of Patrick T. Jackson, Kirk Boott, Warren Dutton, Paul Moody, John W. Boott, and myself. We perambulated the grounds, scanned the capabilities of the place, and the remark was made that some of us might live to see the place contain twenty thousand inhabitants.<sup>8</sup>

East Chelmsford, at that time, had a population of about four hundred.<sup>9</sup> Small scale industrial development had continued in the basically rural area, since the building of the Pawtucket Canal. The land along the lower Concord River was dotted with mills, one of which manufactured cloth. Phineas Whiting and Josiah Fletcher built a mill in 1813, on the west side of the Concord, upstream of the Pawtucket Canal locks. They leased it to John Goulding, who spun cotton, carded wool, and made textile machinery there. In 1818, Thomas Hurd bought the mill and began manufacturing woollens.<sup>10</sup>

Before 1821, the Pawtucket Canal supplied water to small mills near the Concord. When Joseph Tyler began work on the canal in 1793,

he recongized that water brought from above the Pawtucket Falls, through the canal, had the potential to power mills, as well as float rafts of timber. The following request appears in the directors' records: "Mr. Tyler makes request that if, at any future day, the Directors shall think fit to permit any mills to be erected on the canal, he may have the preference in having such privilege."<sup>11</sup> After his death, the directors granted two such privileges.

In 1815, John Goulding got permission to build a small mill "on the margin of the canal," but only "as an experiment." The directors stipulated that the mill would "be removed at their pleasure" and that water shall, in no case, be taken from the canal, when it shall be found injurious." The site was on the north side of the canal, at the lower locks. Goulding drew water from above the locks, dropped it through his waterwheel, and let it flow down a depression into the Concord. He later wrote that he "made machinery there; helped fit up Hurd's mill. I moved from there, just before the Canal Company sold out to the present owners, who came in possession and established Lowell." Nathan Tyler built a grist mill just below Goulding's mill, and both buildings appear in the 1821 "Plan of Pawtucket," and in property maps of the Proprietors of Locks and Canals.<sup>12</sup>

Further up the Concord River, a true power canal was under construction in 1821. Oliver Whipple, superintendent of a gunpowder works, wanted a canal to supply water power for new mills and expanded production. His canal began above the upper falls on the Concord, ran parallel to the river for a third of a mile, then turned west, and

discharged into River Meadow Brook. It was a very narrow canal, holding water almost twenty five feet above the level of the Concord, downstream of the falls. Laommi Baldwin, son of Colonel Laommi Baldwin of Middlesex Canal fame, consulted on this canal project and approved the plan. His brother, George Baldwin, drew a map, in 1825, which shows the northern half of the canal with three miles beside it.<sup>13</sup>

The Pawtucket Falls of the Merrimack River could provide much more water power than all the small falls of the lower Concord. Water could supply energy, because of its position (elevation), its velocity, and its pressure. Since energy is the ability to do work, water possessing energy is a potential source of useful power. Water dropping over a fall gives up energy of position, as it moves to a lower level. Much of this energy can be made to do work for man, and for centuries, men harnessed the energy of falling water with various types of wheels.<sup>14</sup>

The first water wheels operated in moving streams and drew energy from the water as it struck their blades. These primitive and inefficient "float wheels" made use only of energy due to the velocity of the water. The development of undershot wheels brought improved efficiency, but still meant that energy was exerted by the impact of moving water. However, some millwrights began to use a fall, in the form of an inclined raceway, to increase the velocity of water, by striking the paddles of their undershot wheels. With the introduction of the breast and overshot wheels, the fall became important. These

wheels made use of the energy due to elevation and to the force of gravity. They carried water in their buckets from an upper level to a lower level, with the weight of the water applying energy directly to the wheel.<sup>15</sup>

Breast and overshot wheels were twice as efficient as undershot wheels. This proficiency is a measure of the ability of a wheel to utilize the theoretical power of the water. One hundred percent efficiency, impossible because of unavoidable hydraulic and mechanical friction losses, would mean complete energy transfer or power utilization. The competence of any type of wheel varies with its size and design, but the most advanced breast wheels of the early nineteenth century were usually about sixty percent efficient. These were so-called "high breast wheels," in which the water entered buckets near the top of the wheel. All breast wheels, unlike overshot wheels, rotated "backwards," or towards the sluice which delivered the water.<sup>16</sup>

Paul Moody, skilled mechanic and self-taught engineer of the Waltham Mills, preferred high breast wheels for the new mill sites being planned at East Chelmsford in the early 1820s.<sup>17</sup> The available water power was enormous, for the Pawtucket Falls provided a possible drop of at least thirty feet, and the river had a tremendous flow rate. Water power can be measured by a certain volume of water flowing in a given unit of time over a specific drop. The available power increases with the drop, which hydraulic engineers call the "head," and with the flow rate.

Mills could be built at some distance from a fall or canal(s). The Pawtucket Canal was larger than Whipple's power canal and, with modification, could handle a flow rate sufficient to power a number of mill complexes. Its curving path was not advantageous for the placement of mills, but a sizeable work force could dig one or more new canals running from it to the best mill locations. Boott, Moody, Jackson, and Appleton were thinking of these possibilities, as they formed the Merrimack Manufacturing Company on December 1, 1821.<sup>18</sup>

The formation of the Merrimack Manufacturing Company took place while Kirk Boott was still buying up stock in the Pawtucket Canal, as well as land and water rights in East Chelmsford. The articles of agreement bound the six original subscribers together and made Kirk Boott the treasurer and agent of the company. He was not the largest shareholder, but a chief executive with a major interest in the company. He and his brother, John Boott, held ninety shares each. Appleton and Jackson had one hundred eighty each, and Moody had sixty.<sup>19</sup> Article six of the agreement set out immediate tasks for Boott to accomplish:

Whereas, we have been informed that the Proprietors of the Locks and Canals on Merrimack River are possessed of valuable Mill Seats and water privileges, and whereas Kirk Boott has with our consent advanced money for the purchase of shares in the stock of that Corporation, and of lands thereunto adjoining, we hereby confirm all he has done in the premises, and further authorize him to buy the remainder of the shares in said stock, and any lands adjoining the locks and canals, he may judge it for our interest to own; and also to bargain with the above named Corporation for all the Mill seats and water privileges they may own. We must, in all cases, be governed by such advice and direction, as he may receive from the Company, or any committee duly appointed by them.<sup>20</sup>

Within a week, other stockholders were added, by transferring some of the original six hundred shares. One hundred and fifty went to the Boston Manufacturing Company, many of whose proprietors were involved in the new venture. The six hundred shares represented a large amount of potential capital, for assessments up to one thousand dollars per share were allowed in the articles of agreement. Soon, stockholders were being assessed to pay for Boott's purchases.<sup>21</sup>

The first official communication between Kirk Boott and the Proprietors of Locks and Canals was read and considered at a directors' meeting on November 14, 1821. The minutes referred to Boott as the "agent of a Company who propose to establish large mill works in a manufactory." He expressed "a desire to purchase of the Proprietors of the Locks and Canals on Merrimack River all the mill power they own at Chelmsford." Thomas Clark, one of the directors, and also Boott's secret agent, in the purchase of land and stock, was appointed by the directors as an "agent in behalf of the Corporation to confer with the said Boott...."<sup>22</sup>

Clark brought Boott's offer to a directors' meeting on December 26, 1821. It contained two separate proposals:

I am authorized to offer you \$1,800 per annum (for the mill power and all the land the Proprietors of the Locks and Canals on Merrimack River own and which is not necessary for the use of the Canal) reserving the right to pay thirty thousand dollars, in lieu thereof, whenever I may find it convenient or giving ninety days notice - on condition that the canal shall be so enlarged by the Proprietors that we may, at all times, have sufficient water and that the locks be rebuilt of stone in such manner that tye (sic) will not require frequent repairs. -- Or I am authorized to make the following proposal -- we will, at our expense, raise the dam

at the Swamp Locks, as to render the Mink Locks unnecessary, provided it can be done at a reasonable expense - and will deepen the water in all that part of the Canal above the Swamp Locks, and enlarge the same and keep it in repair, if the Proprietors will give us liberty to take another Canal out above the Swamp Locks for our own use. -- We agreeing, at the same time, not to draw water without leaving sufficient for the use of the Canal.<sup>24</sup>

(signed) Kirk Boott, Agent

All the Proprietors met that same day, and four of the five directors of the corporation resigned their positions. Apparently, Boott had acquired enough shares to control the corporation, and chose to elect new directors. Elected were William Appleton, Ebenezer Appleton, Patrick Jackson, and Kirk Boott, himself. On January 8, 1822, Boott became clerk pro tem, and within two months, was both clerk and treasurer of the Proprietors of Locks and Canals.<sup>24</sup>

When the members of a committee, appointed by the old directors, reported their opinion of Boott's proposals to the full proprietors' meeting on January 17, 1822, they could hardly have expected a sympathetic hearing. The committee urged the rejection of his proposals; the proprietors voted to reject the report and to accept the second of Boott's propositions. Boott, as acting clerk, recorded the results of that meeting. The Proprietors of Locks and Canals were then completely controlled by the Merrimack Manufacturing Company, although the older canal company still had an independent legal charter. Boott's account with the Merrimack Manufacturing Company, in February, contained \$30,217, paying for 339 of the 600 total shares in the Proprietors of Locks and Canals.<sup>26</sup>

Boott's account also contained \$18,339 for land purchased in East Chelmsford, near the canal.<sup>27</sup> Thomas Clark, his agent, had bought seventeen parcels of land, during the month of November 1821, before word of Boott's intentions were made public. Almost two hundred acres of this land came from the farms of Moses Cheever, Nathan Tyler, and Josiah Fletcher. During January 1822, Boott made four purchases in his own name, but, by March, the Merrimack Manufacturing Company was acquiring land openly as a corporation. The company soon held title to most of the land between the Pawtucket Canal and the Merrimack River, as well as sections adjacent to and south of the canal.<sup>28</sup>

One individual did cause some trouble for Boott and his program of inexpensive land acquisition. Thomas Hurd, who had a woolen mill on the Concord River, learned of Boott's plans in time to buy up some land and water rights which the Merrimack Manufacturing Company needed. On November 27, 1821, he bought Bowers' Mill at Pawtucket Falls, just before Boott was about to purchase it. He later bought other parcels of land in or beside the falls, and drove a hard bargain with Boott for all these important sections. On August 8, 1822, he sold six lots and his mill rights at Pawtucket Dam. The Merrimack Manufacturing Company paid him \$18,000, a comparatively high price, for a total of less than twenty eight acres and some mill privileges.<sup>29</sup>

Control of the Proprietors of Locks and Canals, and ownership of large amounts of land, gave the Merrimack Manufacturing Company the legal right to enlarge the Pawtucket Canal, choose a site for the first

mill, and begin the construction of a branch canal to that site.  
The new company had the necessary finances and engineering talent  
for the ambitious project it began in 1822.

FOOTNOTES CHAPTER II

- [1] See Nathan Appleton, Introduction of the Power Loom, and Origin of Lowell (Lowell, 1858), pp. 7-9, 14; and Samuel Batchelder, Introduction and Early Progress of the Cotton Manufacture in the United States (Boston, 1863), pp. 65, 68, 106-107.
- [2] Appleton, Introduction of the Power Loom, pp. 15-16.
- [3] Ibid., pp. 17, 25.
- [4] Ibid., 16-18.
- [5] See George Rogers Taylor, "Introduction" to The Early Development of the American Cotton Textile Industry (New York, 1969), p. xxxii; George Gibb, The Saco-Lowell Shops; Textile Machinery Building in New England 1813-1949 (Cambridge, 1950), p. 742 n; and James Montgomery, The Cotton Manufacture of the United States Contrasted and Compared with that of Great Britain (Glasgow, 1840), p. 163.
- [6] Correspondence Between Nathan Appleton and John A. Lowell in Relation to the Early History of the City of Lowell (Boston, 1848), pp. 14-15.
- [7] See Locks and Canals, "Plans and Deeds of Some of the Land Acquired by P.L. & C 1792 to 1928," p. 1; and Appleton, Introduction of the Power Loom, pp. 18-19.
- [8] Appleton, Introduction of the Power Loom, p. 19.

- [9] Compare figures given by Henry Miles, Lowell As It Was, and As It Is (Lowell, 184?) pp. 19, 59; and Z. E. Stone, "Before the Power Loom: The Earliest Cotton and Woolen Industries at East Chelmsford and Vicinity and Their Promoters," CORHA, VI, 67-68. Stone seems more accurate.
- [10] See Wilkes Allen, The History of Chelmsford (Haverhill, Massachusetts, 1820), pp. 84-86, 97; John Goulding to Josiah French, 4 April [year?] in CORHA, I, 263; and Lowell Journal, 9 March 18??
- [11] Locks and Canals, Directors' Records, 23 February 1793.
- [12] See Ibid., 11 May 1815; Locks and Canals, "Plans and Deeds," maps for deed 7, 8, and 66. Goulding to French, CORHA, I, 263; and S. A. Drake, History of Middlesex County (Boston, 1880), II, 55.
- [13] See J. W. Meader, The Merrimack River; Its Source and Its Tributaries (Boston, 1869), p. 264; and Locks and Canals, George Baldwin
- [14] A good introduction to hydraulics is Civil Engineering: Materials, Hydraulic Waterwheels, vol. 399 of the International Library of Technology (Scranton, 1925). The volume is a compilation of early twentieth century correspondence courses from the International Correspondence Schools. For a more thorough text, see Daniel Mead, Water Power Engineering (New York, 1908
- [15] Mead, Water Power Engineering, pp. 1-3.
- [16] See Mead, 21-23; and Charles T. Main, "Evolution of the Transmission of Water Power," in Lamb's Textile Industries of the United States, ed. by E. E. Foster (Boston, 1916) Vol. I, 224.

[17] See Appleton, Introduction of the Power Loom, p. 24; and Locks and Canals (L. T.), Drawer [?] of Merrimack Company Mill, 1822.

[18] Merrimack Manufacturing Company, Directors' Records, 1 December [year?]

[19] Ibid.

[20] Ibid.

[21] See Ibid., 7 December 1821, 8 December 1821, 28 February 18 [??]; and Appleton, Introduction of the Power Loom, pp. 22-23.

[22] Locks and Canals, Directors' Records, 14 November 1821.

[23] Ibid., 26 December 1821.

[24] Ibid., 26 December 1821, 8 January 1822, and ?March 1922.

[25] Ibid., 17 January 1822.

[26] Appleton, Introduction of the Power Loom, p. 23.

[27] Ibid.

[28] Locks and Canals, "Plans and Deeds," pp. 1-3 and the overall plan of the lots.

[29] See Ibid., deeds #27-33; and J. T. Spof\_\_\_\_\_ to Mr. Gilman, 13 November 1872, Mss, in Rare Book Room, Lowell Technological Institute.

## CHAPTER III

The topography of East Chelmsford and the shape of the old Pawtucket Canal placed limitations on the industrial and urban planning of the Merrimack Manufacturing Company. The ideal plan for an industrial community with water-powered mills requires the construction of a canal running parallel to a river with a falls. If the canal leaves the river above the falls and reenters at some distance downstream, then the land between the canal and the river becomes an island on which mills can be placed.<sup>1</sup> By keeping the level of water in the canal close to that of the river above the falls, there will be a major difference in water level between the canal and the river. In this way, the potential energy of the water, due to its elevation, or head, can power manufacturing processes in each mill.

For ideal urban development beyond the canal and island of mills, the river should run straight. In the early nineteenth century, most urban planners preferred a street pattern based on a rectangular grid. Streets carefully spaced and intersecting each other at right angles had an orderly appeal that most communities found irresistible. A town built beside a river usually had a straight main street, roughly parallel to the river bank. Other streets form a gridiron, with the main street as one axis.<sup>2</sup>

East Chelmsford was not suitable for a complete application

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of the ideal plan. The Pawtucket Canal was already in place, forming a wide arc around the bend in the river. The canal was not even close to the Merrimack, at any point below the falls, and would need not only a supply of water, but also a lower level waterway, into which they could discharge the flow from their wheel pits. There must be a drop between the level of the head race and the level of the tailrace, if gravity is to provide the power for turning a waterwheel.

In the ideal plan, the mills line the bank of the river below the falls, the headraces from the canal enters the buildings near the top of their foundations, and the tailrace exit at the lower level of the river. In East Chelmsford, the land on the south side of the Pawtucket Falls rose steeply from the river. Mills could not be built above the level of the upper river and still use its water power; nor could a new canal be cut parallel to the river without surmounting the problems of rising ground and solid rock ledge. Mills could line the bank of the Merrimack, but they would have to stand at or beyond the great bend, where the land surface was not too high.<sup>3</sup>

The selection of a site for the first mills was a crucial engineering decision. Nathan Appleton explained that "It was decided to place the mills of the Merrimack Company where they would use the whole fall of thirty feet. Mr. Moody said he had a fancy for large wheels. The land along the Merrimack, just past the bend, was suitable, but only if a new branch canal could be cut to deliver the

necessary water. Recognizing this problem, Kirk Boott submitted a proposal for taking "a new Canal out above the Swamp Locks."<sup>4</sup> The old Pawtucket Canal would be enlarged and serve as a feeder for the new power canal, which would run from the Swamp Locks basin, in the shortest line toward the river. This canal could supply a group of mills placed approximately two thirds of the distance from the Great Bend to the junction with the Concord River.

Boott suggested altering the Pawtucket Canal to keep the water at a high level, all the way to the new power canal. There would no longer be a drop at the Minx Locks. Even with the expected friction head losses in the enlarged Pawtucket Canal and the power canal branching from it, water would reach the mills of the Merrimack Manufacturing Company at an elevation of thirty feet above the river. Paul Moody realized that this head and the flow rate possible for the proposed canals meant a great deal of available water power for textile production.<sup>5</sup>

The directors of the Merrimack Manufacturing Company authorized Boott, their agent, to put these plans into effect. Enlargement of the Pawtucket Canal and construction of a new branch canal commenced in the spring of 1822, with Boott personally supervising the project. Moody, still the chief engineer at Waltham, helped with the problems of hydraulic engineering, but could not spend as much time on the site as could the resident agent. Patrick Tracy Jackson, who had gained engineering experience while superintending the Waltham mills, also

took an active interest in the canal work at East Chelmsford. Boott's execution and engineering skills received close scrutiny during this initial phase of construction.

Kirk Boott was an imperious, authoritarian figure, with some training in engineering and surveying. Born in Boston in 1790, he spent part of his youth at the Rugby School in England. After reaching his senior year at Harvard, but before graduation, Boott took a commission in the British Army. He served in the Peninsula Campaign as an infantry lieutenant, but refused to accompany his regiment to America, during the War of 1812. Returning to England, he apparently attended either Sandhurst or Woolwich, both Royal military schools.<sup>6</sup> Several biographical sketches refer to his studying military engineering, but neither school, at that time, had adequate courses in that field. More likely, he spent time examining English engineering projects, talking with and helping professional engineers, and studying on his own.<sup>7</sup> These were the methods often used by Americans, to acquire a knowledge of engineering and surveying, in the first half of the nineteenth century.

Jackson and Appleton demonstrated their confidence in Boott, when they selected him for the post of agent. His family, like theirs, was prominent in the Massachusetts mercantile community. He wanted to move into the manufacturing field and, therefore, eagerly accepted the challenge they offered him in East Chelmsford.<sup>8</sup> Although they had to delegate considerable authority to the ambitious young man, they could watch his performance and, thus, count on the able assistance he would

receive from Paul Moody. Boott might claim a familiarity with engineering, but Moody was a proven mechanical genius.

Moody was born in Newbury, Massachusetts, in 1779, and became a hand weaver by the time he was sixteen. His obvious mechanical talents soon brought him positions as machine-builder and designer. When Francis Cabot Lowell hired him in 1814, he was already part owner of a satinet mill in Amesbury. He was largely responsible for the setting up of the first Waltham mill and the development of machinery, which made it a manufacturing success.<sup>9</sup>

At Waltham, Paul Moody worked not only on textile machinery, but also on the power-producing equipment in the mills. The Reverend Bagnall, a noted nineteenth-century historian of the textile industry, described Moody's involvement in the design of a control mechanism for the breast wheels:

Another illustration of the mechanical genius of Mr. Moody was his construction of a "governor," on the suggestion of Mr. Lowell, who, on the occasion of a visit of Mr. Moody at his house in Boston, said that "they must have a governor, to regulate the speed of the wheels." Mr. Moody had never heard of such an apparatus, and all the information which Mr. Lowell could give him was that, having seen one in England, he remembered there were two iron balls suspended on two rods, connected at one end like a pair of tongs. When the wheel was in too rapid motion, these balls would be driven apart, and produce a partial closing of the gate; when, on the other hand, the motion was too slow, the balls would approach each other and the gate would be opened more widely, letting in a larger volume of water and increasing the speed of the wheel. It was understood, when Mr. Moody left the house of Mr. Lowell, that a "governor" should be ordered from England. On his ride from Boston to Waltham,

Mr. Moody could think of nothing but the "governor," and the next morning, when going to the machine shop, he chalked out a sketch of his idea as a model for his workmen. Not long afterwards, Mr. Lowell, while in Waltham, made an inquiry as to whether the "governor" had been ordered from England. After being informed that it had not been ordered, Mr. Moody produced the "governor," which had been made under his direction. It was, at once, set up in the mill, where it gave service until 1832. It was the model of those produced in Lowell, after that time.<sup>10</sup>

Moody also apparently took an active role in the designing of the early water power system of the Merrimack Manufacturing Company. Appleton regarded him as the authority on the capacity of the canals and their water power potential. In an 1823 estimate of the East Chelmsford holdings, Appleton accepted Moody's observation on the enlarged Pawtucket Canal and the new branch canal.<sup>11</sup> Moody may indeed have been as valuable to the company as a hydraulic engineer, as he was as a designer of textile machinery.

In the 1820s, hydraulic engineering was still a new field in America. Although large projects, like the Erie Canal, provided practical experience for some beginning engineers, few men were well-trained in it. Soon after becoming the agent of the Merrimack Manufacturing Company, Kirk Boott corresponded with one of the Erie Canal's well-known engineers, Myron Holley. In a letter written in December 1821, Holley gave Boott advice on the construction of dams and locks.<sup>12</sup> By then, Boott had already proposed rebuilding the Pawtucket Canal locks with stone,<sup>13</sup> a decision which may have been based on the record of the nearby Middlesex Canal. Boott and Moody had seen the fine stonework of the three locks in Middlesex village,

and knew that these locks had proven far superior to the rotting wooden locks used elsewhere on the Middlesex, and exclusively on the old Pawtucket Canal.

Once he had recruited enough laborers, Boott began work to change the dimensions of the Pawtucket Canal, from the river entrance to the Swamp Locks. The goal was a uniform rectangular cross section sixty by eighty feet.<sup>14</sup> This was not the most efficient shape for a channel, intended to carry water for power generation, but there were sound economic and engineering reasons for choosing it. In terms of pure hydraulic efficiency, a canal should present as little surface area in contact with the moving water as possible. The term "wetted perimeter" is used to define that part of a canal's cross-section which actually contains the water. Canals with the same cross-sectional area, or capacity to hold water, may vary in the extent of this wetted perimeter, because of differences in shape.<sup>15</sup>

A canal with a semicircular cross section has the optimal shape for efficient movement of water, but was difficult to construct and maintain in the nineteenth century. Half a hexagon, a regular trapezium in precise geometric terms, has a greater wetted perimeter than a semicircle of equal area, but is more efficient than a half square or other shallow rectangle. A trapezoidal canal shape was usually preferred in soft earth, because of its high efficiency and the stability of its sloping sides. In rock ledge, however, the sloping sides could be a liability for canal builders.<sup>16</sup>

Blasting techniques for excavation in stone ledge were more suited for the production of a vertical wall than an inclined one of uniform slope. The wall, left after vertical drilling and blasting in stone, was often strong enough to stand alone. Masonry work, which made the walls of rectangular canals very expensive in most soils, was reduced when natural rock could be left as part of the vertical sides. Also, costs of masonry were less, whenever broken stone from excavation in ledges could be used as construction material in the laid walls.<sup>17</sup>

Rock ledge was present near the surface of much of the land in East Chelmsford. Deep excavation would have been expensive, and for a canal of given width, any trapezoidal shape would have required a deeper cut than a rectangular shape with equal cross-sectional area. If maximum depth was held constant, only by increasing the width of a canal could a trapezoidal shape be designed to hold as much water as a rectangular one. A wider surface was not advisable, because it would use up valuable land and increase overall friction in the canal during cold weather. Once a canal froze over, the underside of the ice surface was in contact with the moving water and had to be considered an addition to the normal wetted perimeter.<sup>18</sup>

Thus, in the particular situation existing in East Chelmsford, a power canal of rectangular cross section was both economical to construct and very efficient in year-round operation.<sup>19</sup> The contractors working on the Pawtucket and branch canals were not always able to cut the precise cross sections requested of them, but in most cases, they

created a rough approximation of a rectangular shape. Difficult rock ledges were sometimes left jutting into the channel, because of the urgent pace of construction; therefore, a few sections of the first branch canal remain irregular to this day. Boott was apparently willing to compromise, in order to remain on schedule and not delay the opening of the first mill.

At least five hundred laborers worked on projects connected with the enlargement of the Pawtucket and the digging of the branch canal to the Merrimack mills. Most were hired by contractors who made financial agreements with Kirk Boott to complete specific tasks. Charles Blaney and Hugh Cummiskey brought large work gangs of their own Irish countrymen to East Chelmsford. Cumminsky walked from Charlestown, Massachusetts, with thirty men in April 1822. They were to work on the canals, but according to local tradition, the Irishmen arrived too tired to begin digging. Kirk Boott is said to have followed Cummiskey's suggestion and bought the men a drink in a nearby tavern. Refreshed, they grabbed their shovels and went to work.<sup>20</sup>

Dr. John O. Green, physician to the canal laborers, remembered, late in life, that much of the excavation, in the spring of 1822, was for the foundations of the first mill, and the new branch canal, later named the Merrimack Canal. The workers had barracks near Dutton Street until early June, when the corporation moved the expanding labor force to two large barns "fitted up with bunks for sleeping and rough tables for feeding." The enlargement of the Pawtucket apparently became

the primary project, at that time, and required the recruitment of several hundred additional men.<sup>21</sup>

As the Irish came in increasing numbers, a separate Irish community began to form. The Merrimack Manufacturing Company soon lost interest in providing even rudimentary housing for the day laborers. Irish families moved into East Chelmsford and took shelter in makeshift huts on a patch of company land known as "the Acre" or "the Paddy Camps." Dr. Green recalled waiting on the sick "in their wretched dwellings... with an umbrella over my head to shield me from the dripping of a leaky roof." The paternalistic regard for textile workers, which made the "Lowell system" famous, did not extend to the men who built the canals, the mills, and the neat rows of corporate housing. They had to fend for themselves.

In the fall of 1822, J. G. Kittredge saw the laborers at work on the Pawtucket Canal. Although they were undoubtedly a rough group of men, his description of them reveals some of the bias typical of the nineteenth-century New England Yankee:

Hundreds of Irishmen were at work on the canal, digging and wheeling. The banks were lined with stone and mud cabins, with a barrel serving for a chimney. When the canal was finished, they had a grand row, in which shillalahs and stones came in play; but often there was "more bark than bite." At times, however, they would get so excited that the authorities would notify a priest, who, in turn, would disperse them at sight. Many of the boys from the adjacent towns, who were not familiar with the manners and customs of the Irish people of those days, gathered near the Irish settlement to see the sport. Craving excitement, they became very high-spirited, and freely indulged in drinking.<sup>23</sup>

Work on the Pawtucket Canal was both hard and dangerous, some six thousand pounds of powder were used to blast stone ledges.<sup>24</sup> Men worked with hammers, drills, shovels, and wheelbarrows along the canal bottom, while teams hauled out tons of earth and rock. Stone masons laid side walls, where necessary, but often relied on cut or natural ledge formations to form part of the canal's sides. In the swampy sections, the canal had to be narrowed and strong banks formed to restrain the flow. This muddy work was as onerous for the workmen as excavation.<sup>25</sup>

Dr. Green realized that "the nature of their employment exposed them to frequent accidents and disease." His medical practice was "extensive among them, both night and day," being the first to be notified when accidents occurred:

On the eighth of July, the greatest excitement was caused by a man being, as it was termed, blown up by gunpowder in blasting rocks. It was the beginning of a series of similar and frequent accidents. On the sixteenth, another occurred, and on October 15, Russell Mears of Tewksbury, whose case was peculiar, had made three holes. Having charged two of them and tampering with the third, the latter exploded, throwing him into the air. He fell near the other holds, which exploded in succession. No one could approach him until afterwards. He lost an arm and an eye, and was pierced in all directions by the fragments of stone, some of them weighing two ounces. He recovered, however, after months of suffering and much of my anxious care. These accidents were so frequent that I had, in two years, five amputations of arms, with one individual losing both hands.<sup>26</sup>

Rebuilding the locks of the Pawtucket required even more technical skill than the work on the open channel. Because of extensive decay, Boott had to tear out all the wooden locks; only

three were then rebuilt. By the raising the dam at the Swamp Locks and deepening the upper channel, he dispensed with the old Minx Locks and avoided any change in water level at that point. He and Moody planned an upper level, approximately thirty feet above the lower Merrimack River. They then established a drop of thirteen feet at the Swamp Locks, leaving seventeen feet of head in the lower level of the Pawtucket.<sup>27</sup>

Boott wanted stone construction for the walls of his new lock chambers. His work crews built the solid chambers he asked for, but lined them with wood to make them water tight. They made heavy timber gates with paddle valves to let water in or out of the chambers. The Guard Locks had just one chamber, for only during high water was there an appreciable drop between the upper river and the upper level of the canal. At the Swamp Locks, two chambers were required to carry boats or rafts the thirteen vertical feet between levels. Similarly, the larger seventeen foot drop at the Lower Locks called for two chambers.<sup>28</sup>

The Guard Locks had protected the old transportation canal from freshets in the river, which threatened to wash out its banks and locks. With the Pawtucket serving as a feeder for one or more power canals, the role of the Guard Locks became more complex. The gates of the old lock chamber had spanned the channel, blocking the flow of water from the river, whenever they were closed. This occasional obstruction of the normal flow was no problem for a transportation canal, in which there was little current. A power canal, on the other hand, cannot have brief

blockage of its flow without a rapid drop in water level. Mills, drawing water at a normal rate, would soon drain the canal below the blockage and lose their capability to generate power.

If a canal was to serve as both a transportation and a power system, the passage of transport through the locks could not interfere with the production of water power. The Merrimack Manufacturing Company made sure that nothing interfered with the flow of water to its new mill site. Boott cut a separate channel, bypassing the rebuilt guard lock. The main flow then ran on the other side of a small island from the lock chamber. To protect the canal from freshets and to maintain a set level, sluice gates, crossing the canal, were erected. These gates controlled the flow into the system and enabled company employees to adjust the water level, by varying the volume of water admitted per second.<sup>29</sup>

At the Swamp Locks, Boott insured that a flow of water could bypass his new lock chambers. He built a dam to maintain a thirteen foot drop between the upper and lower Pawtucket, and to allow water to spill over into the lower level. This dam created the two level arrangement of the canal, but until other branch canals could be constructed, the drop at the Swamp Locks produced no water power. The same situation existed at the lower end of the Pawtucket, where the flow dropped into the Concord River without useful effect.<sup>30</sup>

Boott also built a dam at the Lower Locks, holding the canal level seventeen feet above the Concord and allowing the spillage of water out.

of the canal. He then hired Deacon Rand, a contractor from Vermont, for the difficult job of moving and laying heavy stones for the lock walls. J. G. Kittredge, who worked with Rand on the project, has left us a detailed account of Rand's activities in Lowell.<sup>31</sup>

In early April 1823, Rand arrived with a large baggage train of ox carts. He and his personal crew of about twenty young Vermonters brought with them "all the implements suited to his peculiar work." The most impressive piece of equipment was "a pair of high wheels," which attracted a large crowd, as they rolled into East Chelmsford.

They were certainly eight or ten feet in height, and greatly astonished "the down-easters," as the strangers called us. These wheels were sustained by a very large axle, and it was this that retarded their arrival somewhat, as the men who came with them were obliged to widen the road, in places, by digging away embankments, moving rocks and stumps, cutting trees, etc., to open a way for them.<sup>32</sup>

The huge wheels were for moving heavy rocks. Deacon Rand and his men were soon at work, selecting suitable stones on land near the Lower Locks. They then used the wheels in the following manner:

His men would dig around the large boulders, to get a chance to make fast a chain, or insert a clevis in the top into which they could hitch, and then place the big, strong wheels astride them. With the lifting apparatus attached to those wheels, one man could raise stones weighing several tons each, and one or two yoke of oxen would easily convey them to the place where they were wanted, where they were lowered to a platform, and then, by means of rollers, carried to the place for which they had been selected. All stone too large to be loaded into a cart were put upon a sort of platform, suspended between the two great wheels, and thus, carried to the canal. The large boulders, referred

to, could not have been moved from their pits, at that time, in any other way than that which I have attempted to describe.<sup>33</sup>

Rand built the lock walls "of large and small stones laid without mortar." Most of his work is still in place today, with stones weighing up to ten tons in the massive rubble walls. The lock chambers had to fit the specifications in the 1792 charter of the Proprietors of Locks and Canals, which states that rafts of timber "not exceeding twenty-five feet in width, and one hundred feet in length" must be accommodated. Boott followed these legal requirements in his plans, and Rand carried out his instructions to the letter.<sup>34</sup>

Deacon Rand was highly successful, because of his technical expertise, his equipment, and his very loyal labor force. Unlike most contractors, he treated his men like members of a large family. While working on the Lower Locks, they lived and ate with him. Rand even supplied his men with a drink called "Blackstrap," which was a combination of New England rum and molasses. Kittredge recalls the Deacon passing a pitcher of "blackstrap" around the large breakfast table every morning, before work commenced.<sup>35</sup>

By the end of 1823, the Deacon had finished his work for Boott. He was far ahead of schedule, but there was some confusion over how much Boott owed him. The contract called for payment by the perch of stone laid, Boott figuring a perch was sixteen and a half cubic feet. Rand informed him that a perch was sixteen and a half feet,

equivalent to an English rod. Boott, who was supposed to be an able surveyor, was embarrassed to learn that Rand was correct. He therefore paid the canny Vermonter several thousand dollars more than he had intended. The Merrimack Company records show he received \$9,833, in 1823, for laying the walls of the Lower Locks. Rand then went back to Vermont, only to return in 1826 to build the piers and abutments of the Central Street Bridge.<sup>36</sup>

While work on the Pawtucket Canal and its locks was underway in 1822 and 1823, men were also finishing the Merrimack Canal. The route, from the Swamp Locks to the Merrimack Manufacturing Company mill yard, was a straight line, perpendicular to the river bank. At the mill yard, the finished canal turned northwest (parallel to the river), and came to an end. The directors of the company planned more than one mill and wanted to build them between the short final section of the canal and the river.<sup>37</sup>

The Merrimack Canal, although narrow and shallow, was very hard to build. A tough rock ledge between the present Merrimack and Market Streets caused a great deal of trouble. Few men were experienced in rock blasting, at that time, and the ledge apparently resisted many determined efforts. When completed, the three thousand, four hundred foot canal still had very rough walls and bottom. Despite later efforts to improve the canal, its shape in cross section was still listed as irregular, at the end of the nineteenth century.<sup>38</sup>

In early September, 1923, the enlargement of the upper Pawtucket and the construction of the Merrimack Canal had progressed to a point where water could be let into the canals. When all the work on the locks and both canals was completed in the following year, the accumulated costs of construction were very high. According to Nathan Appleton, work on the Pawtucket Canal and locks alone cost about \$120,000. The records of the Merrimack Manufacturing Company give a combined cost of \$150,000 for the Pawtucket, the Merrimack, the locks, and necessary bridges. The company paid one contractor a total of \$17,820.75, between July 1822, and March 1823.

Boott and Moody had the first Merrimack nearing completion, as the water entered the enlarged Pawtucket on September 2, 1923. Two days later, Boott wrote the following dramatic passage in his diary:

Thursday, September 4, 1923. After breakfast, went to factory, and found the wheel moving round his course, majestically and with comparative silence. Moody declared that it was "the best wheel in the world." N. Appleton became quite enthusiastic. In the afternoon, he spent an hour looking at the wheel, after which he returned home by Andover.<sup>40</sup>

The first wheel of the Merrimack Manufacturing Company was very similar to the wheels at Waltham, but on a larger scale. It was a high breast wheel, thirty feet in diameter and controlled by adjustable water gates, linked to a fly ball governor of the type Moody built at Waltham.<sup>41</sup> As in other mills of this period, a combination of gearing and heavy iron shafting transmitted mechanical power from the revolving wheel to each room in the mill.

On October 9, 1823, Moody tried some of the carding machines and

a double speeder. The mill did not have all its machinery in place at this time, but by December 15, Boott could report forty looms started. On January 3, 1824, Boott wrote in his diary, "16 Bales of goods sent off to Boston, being the first lot sent off from the Merrimack."<sup>42</sup>

The new mill was built to house approximately the same amount of machinery as the second mill at Waltham, which had 3,584 spindles, with all the machinery necessary to convert cotton to cloth. The physical dimensions of the two mills were also very similar: the Waltham mill was 150 feet long and 40 feet wide, the Merrimack mill was 156 feet by 45 feet. Both had three stories and a finished attic. In 1824, a second Merrimack Mill, again of the basic Waltham style, went into operation.<sup>43</sup>

Before the first mill was built or the Merrimack Canal completed, Nathan Appleton compiled an estimate of the industrial potential of the Merrimack Manufacturing Company in East Chelmsford. In this undated document, he listed the progress anticipated by March 1, 1824: "7,200 spindles in 2 factories of 3,600 each; a bleachery and printing establishment."<sup>44</sup> The company didn't quite meet this schedule of construction, but these structures were only part of a much grander plan.

Appleton conferred with Moody, before making his long term estimates on water power and manufacturing capability.

Mr. Moody estimates that these canals (the Pawtucket and the Merrimack) carrying 480 cubic feet (Appleton confuses flow with cross section here - the Pawtucket feeder at 60'x8' has a cross section of 480 square feet - flow rate is in cubic feet per second) with a fall of 30 feet - will furnish power to carry 60 factories of 3,600 spindles each (the size of the largest at Waltham), but to be on the sure side, suppose in addition to the two now building, they will furnish power to carry 50 such factories, for the location of which the company own land sufficient, admirably well situated, it will amount to 180,000 spindles with all the apparatus for weaving, etc., as at Waltham.<sup>45</sup>

Moody and Appleton were dreaming of up to sixty factories, similar to the largest factory at Waltham. Appleton thought the great wheel of the first mill would need twenty four cubic feet of water per second, with a thirty foot fall to power the operations of 3,600 spindles and other machinery. Experience soon showed that twenty five cubic feet per second, on the thirty foot fall, equalled the power expended in the Waltham mill of 3,584 spindles. Moody's estimate that the Pawtucket Canal could carry a flow of water sufficient to power sixty such mills seemed optimistic to Appleton, but later events proved that even Moody far underestimated the potential power of the Pawtucket.

While still an employee of the Boston Manufacturing Company at Waltham, Moody also assisted in planning the canals and new factories in East Chelmsford. By an agreement made on February 28, 1822, the Merrimack Manufacturing Company could use any of the machinery or mechanical improvements that the Waltham group had then or would develop in the future, and was "entitled in a reasonable manner and at reasonable times to the personal aid, direction, and advice of the principle engineer and superintendent of the Boston Manufacturing

Company, at their establishment in Chelmsford..." Since all the proprietors of the Boston Manufacturing Company had stock holdings in the Merrimack Manufacturing Company, this agreement was not surprising. The new company gave fifteen thousand dollars for these privileges and paid for the manufacture of new textile machines at Waltham.<sup>47</sup>

The scale of the planned development at East Chelmsford soon convinced the directors of the Merrimack Manufacturing Company that they needed the full time services of Paul Moody and a large machine shop of their own. In August 1823, an arrangement was made in which the Boston Manufacturing Company agreed to move their machine shop to East Chelmsford and sell all their patents to the Merrimack Manufacturing Company. The patterns at Waltham and "such of the tools and implements belonging to the Boston Manufacturing Company as may not be wanted by them for their own use" were to go to the new shop. Most important in the agreement was the section on Paul Moody:

It is agreed that the agreement now subsisting between the Boston Manufacturing Company and Paul Moody shall be given up and cancelled, and the said Moody be left at liberty to make a new agreement with the Merrimack Manufacturing Company.<sup>48</sup>

Moody was too valuable to be traded away lightly, however, the Boston Manufacturing Company retained the right to consult him and to use "all inventions and improvements" he might make in East Chelmsford. The Merrimack Manufacturing Company paid seventy five thousand dollars for Moody, the shop materials, and the patents.

With the older company's blessings, other mechanics went with Moody. Once the machinery for the new Merrimack Manufacturing Company mills was built, the shop at Waltham would no longer make plans for large manufacturing operation. The owners of the Boston Manufacturing Company stood to profit in the success of the East Chelmsford development, mainly because they were owners, as well as shareholders, in it. No one got hurt in the arrangements between the two companies; in reality, one company was an expansion of the other.<sup>49</sup>

Moody set up the new machine shop in East Chelmsford, and took charge of its manufacturing operation. The site chosen for the shop was near the Swamp Locks, on a triangle of land between the upper level Merrimack Canal and the lower level of the Pawtucket. By digging raceways from the Merrimack Canal to thirteen foot breast-wheels in the shop, then discharging the water into the lower Pawtucket, Moody used the difference in water levels between the two canals to generate mechanical power.<sup>50</sup> This was the first use of the two level canal system because the Merrimack mill used the full thirty foot potential, thus discharging directly into the river.<sup>51</sup>

By the spring of 1824, the first Merrimack mill was operating, with a second mill nearing completion, and a third under construction. All three sites were linked to the Merrimack Canal and the upper level water supply. The branch canal also powered the machine shop, but the larger Pawtucket Canal carried more volume of water per second than the smaller canal could handle. A large quantity dropped over the dam at the Swamp Locks.

Although the Merrimack Canal was capable of powering more than three mills and a machine shop, it had a limited capacity, which was well known to the planners of the canal system. When Moody was <sup>contemplating</sup> the possibility of sixty Waltham-type mills, he knew that other branch canals were necessary to carry out such a development. The Pawtucket could carry the necessary water, but it was a feeder, not a pure power canal; there were no suitable mill sites on the upper Pawtucket.

After the end of 1821, Boott, Moody, Jackson, and Appleton studied the topography of East Chelmsford and thought of how to utilize the potential power of the Pawtucket Falls. The 1823 Appleton estimate of water power proves that careful planning for a great industrial community was underway before the completion of the first mill.<sup>52</sup> The Pawtucket Canal was not enlarged in 1822 and 1823 to bring water only to the Merrimack Canal, but rather to supply a system of branch canals. When the first mill began production at the end of 1823, planning was apparently still incomplete. However, ideas for new canals went on paper in 1824.

In January 1824, an unknown draftsman drew up two large plans for mills and corporate housing on the south side of the lower Pawtucket Canal, opposite the machine shop. These plans show an intention to narrow and straighten the broad, irregular section of the canal between the Swamp Locks and the Lower Locks. They also show a proposed canal running at the upper level from the Swamp Locks basin, in a line parallel to the lower level Pawtucket Canal. This upper level canal creates an island of the land between it and the Pawtucket. The mills

in the plan are on this land, between the upper and lower level canals. This entire pattern is the same as the ideal power canal plan discussed previously - except on a small scale with the Pawtucket Canal serving as the river and the Swamp Locks dam as the fall. It also incorporates the rectangular grid of the ideal river town in laying out the housing across the upper level canal from the line of mills.<sup>53</sup>

The Merrimack Manufacturing Company meant to build their next set of mills in the area shown on the plans. As Appleton's estimate shows, the company had land and water power in abundance, and had every intention of expanding operations to the maximum extent. On May 19, 1824, the proprietors of the company voted "that the directors be authorized to erect two manufactories at the Swamp Lock with machinery complete, as soon as they judge it to be for the interest of the company."<sup>54</sup>

An undated and untitled plan, which also appears to have been drawn up in 1824, shows another proposed branch canal extending from just above the lower locks to the area near the junction of the Concord and the Merrimack.<sup>55</sup>

A third branch canal was probably planned in 1824, but it first appears in the graphic records as only an applied sketch on an 1825 formal map of the holdings of the Merrimack Manufacturing Company. The sketch shows a canal stretching from the Swamp Locks basin to the area along the Merrimack River, northwest of the company mills. The route is

west of the Merrimack Canal and is a logical path to a number of advantageous mill sites.<sup>56</sup>

By October, 1824, the owners of the Merrimack Manufacturing Company began to have second thoughts about managing these greatly expanded water power and manufacturing operations as parts of a single company, in spite of all the planning for new canals and mills. The company would soon have a total of five textile mills and a print works on its original site by the Merrimack River. In addition, the machine shop, the canals, and over four hundred acres of land created complex business and engineering problems. Kirk Boott, as agent, was doing a masterly job of overseeing all these affairs, but how much longer could one company supervise this expanding industrial community effectively? The owners may also have seen a risk to their financial success in continuing to tie new enterprises directly to the one company. If one or more of the future ventures should fail, the losses would hurt the Merrimack Manufacturing Company as a whole.

On October 19, 1824, the proprietors of the company took the first step toward splitting up responsibility for further development. They appointed a committee to consider the feasibility of reorganizing the old canal company and selling it the water and land needed for the textile operations of the Merrimack Manufacturing Company.<sup>58</sup> While this committee carried out its study, the company directors considered a plan to let another textile company join them in East Chelmsford.

The directors met on November 23, 1824, and decided to make a bargain with a newly formed textile business, the Hamilton Manufacturing Company, "for the sale of one or more mill powers, including machinery and land at the rate of thirty dollars per spindle, and for the sale of any mill powers without machinery, for four dollars per spindle." The site of the proposed site was beside the lower Pawtucket Canal, on part of the land set aside for factories in the January, 1824, plans of the Merrimack Manufacturing Company. The Hamilton Manufacturing Company was not, of course, owned by a group of strangers; prominent stockholders of the older textile company helped form the new one.<sup>59</sup>

Patrick Tracy Jackson explained the non-competitive nature of the Hamilton Manufacturing Company at its inception:

There was a proposition made...yesterday for the formation of a new Company to be established at Chelmsford, to purchase their machinery, water power, and land of the Merrimack Company--The object will be, to make twilled Cotton goods--a different article from anything we have yet attempted--This will be entirely separate from all our other works and under different managers--but is thought so well of, that, I think, all our proprietors, who feel able, will take stock in it.<sup>60</sup>

Next, the Merrimack Manufacturing Company moved to divest itself of all holdings not directly involved in textile manufacture. Apparently acting on the suggestions of the committee appointed in October, the proprietors of the company voted on February 28, 1825:

That William Appleton and Kirk Boott be a committee with full power and authority to settle the terms, conditions, and mode of conveyance upon which the Merrimack Manufacturing Company shall sell and convey to the Proprietors of the Locks and Canals on Merrimack River, the real estate, machine shop, and mill power now belonging to them, the said Merrimack Manufacturing Company.<sup>61</sup>

The 1792 charter of the Proprietors of Locks and Canals was still valid, but the canal company was now wholly owned by the Merrimack Manufacturing Company. Since the takeover in 1822, the canal company had carried on limited business operations, with the powerful textile company actually controlling and paying for canal construction. No new charter was necessary to set up the Proprietors of Locks and Canals as a major company again, and to give it the responsibility for selling the rest of the land and water power held by the Merrimack Manufacturing Company.<sup>62</sup>

The proprietors of the Merrimack Manufacturing Company set up an arrangement, so that the existing 600 shares in the Proprietors of Locks and Canals were split into 1,200 shares. There were also 1,200 shares in the Merrimack Manufacturing Company, and each stockholder could subscribe for as many as he wanted in the canal company, up to the number he already owned in the textile company. In this way, all had a chance to buy into the canal company, and with the assessments they would have to pay on the new stock (set at a total of \$500 per share), they would purchase the land, water power, and machine shop. This capitalization was also sufficient to operate the canal system, until sales of land and water power brought in additional funds. The state legislature approved the arrangement and authorized the

Proprietors of Locks and Canals to proceed with the transactions.<sup>63</sup>

The following tabulation lists the holdings of the Merrimack Manufacturing Company in 1825, and shows the financial transactions involved in the transfer of assets to the Proprietors of Locks and Canals:

Transferred from Merrimack Manufacturing Company to  
Proprietors of the Locks and Canals on Merrimack River:

Locks and Canals stock	\$ 60,000.00	
Water power and factory sites	358,400.00	
Other land (400 acres)	75,000.00	
Machine shop, tools, and buildings	<u>215,016.91</u>	
		\$708,416.91

Less: Property retained by Merrimack  
Manufacturing Company

6 mill powers at \$3.00 per spindle	\$ 64,512	
3 mills with machinery	<u>279,552</u>	
		\$344,064.00

Balance paid in cash by the Proprietors of the Locks and Canals to Merrimack Manufacturing Company:		\$364,352.91
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The term "mill powers" appears among the property retained by the Merrimack Manufacturing Company. A mill power was a convenient unit chosen to represent the amount of water power required to drive the 3,584 spindles and other machinery of the second mill at Waltham. The unit apparently came into use when the sale of water power was first contemplated in 1824. The two Merrimack mills had machinery approximately equal to the Waltham mills, and the Hamilton Corporation also wanted to build two such mills. Payment for the mill sites and water power was set at a rate of four dollars per spindle.<sup>65</sup> The Hamilton Company

purchased two mill powers at that rate; a mill power equaling 3,584 spindles for payment purchases. Actually, a mill power had a more precise meaning in hydraulic terms.

The water power for the second Waltham mill was equal to twenty cubic feet per second over the thirty foot drop used by the Merrimack Manufacturing Company. Each Merrimack mill used this amount of water power, and thus, the idea of a mill power unit was logical, at this time. The Hamilton Manufacturing Company soon purchased, from Locks and Canals, the rights to a flow of water over only a thirteen foot fall, from the upper level of the canal system to a height of thirty feet to the lower level of the Pawtucket at seventeen feet. The mill powers granted to the Hamilton Manufacturing Company were made equal to those of the older company, by increasing the flow to compensate for the smaller drop. The amount of useful mechanical power, generated per mill power on each fall, was approximately the same.<sup>66</sup>

This mill power definition was a local one, based on the practice of the Merrimack Manufacturing Company. Other communities using hydraulic power, later defined mill powers differently, but the power from the Pawtucket Falls was always officially measured in the mill powers established in the 1820s.<sup>67</sup> To calculate the amount of horsepower represented by a mill power, you convert the flow rate to pounds per second, multiply by the drop in feet, and divide by the figure of 550 foot-pounds per horsepower.

$$\begin{aligned} &25 \text{ cubic feet/second} \times 62.33 \text{ pounds/cubic foot} \times 30 \text{ feet} \\ &\div 550 \text{ cubic feet/horsepower} = 85 \text{ horsepower (gross)} \end{aligned}$$

With the efficiency of a high breast wheel estimated at seventy percent, this gross horsepower is converted to sixty effective horsepower. The figure of sixty is given by Nathan Appleton and attributed by him to the engineer, James Francis.<sup>68</sup>

Finding the flow rate, which will give eighty-five gross horsepower on a fall of thirteen feet, is easy, using the above formula. The answer is 58 cubic feet per second. However, the thirteen foot wheels actually got 60.5 cubic feet per second for each mill power. The difference is due to the difference in efficiency between the thirty foot wheels and the thirteen foot wheels. By experimentation, the engineers found that to produce sixty effective horsepower on the smaller drop, you needed 60.5 cubic feet of water per second. The standard mill power was really measured by what it took to run a 3,484 spindle mill in 1824, not by the theoretical potential of the water entering that mill. However, despite later changes in the efficiency of water wheels, the flow rate of water per mill power for each different falls in this industrial community was fixed by the early experiences: 25 cubic feet per second on the thirty foot fall, 45.5 cubic feet per second on the seventeen foot fall, and 60.5 cubic feet per second on the thirteen foot fall.<sup>69</sup>

The Merrimack Manufacturing Company kept six mill powers for the company mills and print works, when it made the great transfer to the Proprietors of Locks and Canals. The Hamilton Manufacturing Company

completed its bargain with the canal company, instead of the textile company. With the purchase, or lease, of two mill powers, the Hamilton Company got a section of land, on which to build its mills. An indenture, officially made in 1826, sets out the mutual obligations in the agreement. The Merrimack Manufacturing Company also had its water power agreement spelled out in an indenture in 1826, but had purchased another mill power by then, for a total of seven.<sup>70</sup> The form of lease for these and later indentures may be found in the appendices.

The Proprietors of Locks and Canals leased water power for an initial payment, which also bought about four acres of land for each mill site, and for a yearly rental fee. The rental fee, in this period, was the nominal sum of three hundred dollars per mill power. "Locks and Canals, as the company came to be known, agreed to supply a specified volume of water per second over a particular fall, and to build and maintain the canals necessary to get this water to the mill sites. The textile company had to pay for its own head races to bring the water to its wheels, and for its own tail races to discharge the water into a river or lower level canal. Since most new companies paid Locks and Canals to build and equip their mills, they often chose to let the canal company build their races, wheel pits, and hydraulic machinery, as well. All this construction on the mill sites was by separate contract with Locks and Canals, and had nothing to do with the indentures for water power.<sup>71</sup>

Kirk Boott remained the agent of both the Merrimack Manufacturing

Company and the Proprietors of Locks and Canals, after the formal division of the two companies. His chief engineer in the canal company, Paul Moody, took responsibility for the machine shop, the canals, and the engineering of various construction projects. Boott, as the senior executive of Locks and Canals, managed the sale of land and water power, and was deeply involved in any business disputes concerning the company's water rights.

Boott carried legal disputes with him from the Merrimack Manufacturing Company to Locks and Canals. The controversy was over mill privileges and legal rights to build a dam at the Pawtucket Falls. Boott thought he had purchased all the existing mill privileges for the Merrimack Manufacturing Company, but a challenge occurred in 1824 and was still unsettled when the textile company transferred its water rights and land holdings to the canal company.

Soon after enlarging the Pawtucket Canal, Boott built a temporary dam at Pawtucket Falls. The makeshift structure, apparently an addition to Bowers' old mill dam, merely linked a series of natural rocks, at the head of the falls, with some wood crib work. This was enough to hold back some of the flow of the river in low water and to maintain a sufficient height of water in the new power canal. However, Boott planned to replace this crude wing dam with a much more substantial dam, stretching completely across the river.<sup>72</sup>

Late in 1824, a short wing dam, of unknown origin, appeared below the main falls, on the north side of the river. Kirk Boott was incensed by this intrusion, into what he considered his company's domain. At first, he blamed Mr. J. B. Varnum, who owned land on the shore near this new dam. Since Boott was about to commence building a massive dam that could withstand even the force of spring freshets, he felt that Varnum was somehow trying to interfere with his plans.<sup>73</sup> The construction of a permanent dam at the head of the falls would certainly destroy the effectiveness of the smaller dam below.

To Boott's extreme dismay, the dam turned out to be another enterprise of the redoubtable Thomas Hurd, the same man who had bought up land and mill privileges in 1821, and had forced Boott to buy them at inflated prices. This time, Hurd had another overlooked mill privilege, purchased from Varnum, and he threatened to sue if Boott blocked his water with the planned dam at the head of the falls. The Proprietors of Locks and Canals inherited the problem after Boott had failed to reach an agreement with Hurd by 1826.<sup>74</sup>

Negotiations between Hurd and Boott grew heated in the first months of 1826. By March, Boott was ready to risk a law suit rather than spend further time in debate. Hurd had actually begun building a mill by his dam, an action which enraged not only the hot-headed Boott, but also the board of directors of Locks and Canals. They promptly approved drastic action.

VOTED: that the agent be authorized to remove part or the whole of the dam built by Mr. Thomas Hurd in the Merrimack River from the Dracut side and employ sufficient hands for that purpose and that the same when done is adopted as the act of the Corporation. This order being passed with the intention to support the rights of the Corporation which Mr. Hurd has infringed by the erecting of the said dam and to enable him if he thinks proper to bring his action at law to try the right of the parties.<sup>75</sup>

Before Boott could carry out this order, he received a final proposition from Hurd, which the directors chose to accept. Locks and Canals agreed to a cash settlement, a land exchange; and the sale to Hurd of two mill powers at twelve thousand dollars each. One of the mill powers was to be drawn from a new canal, which was designed to bring water to the Hamilton Manufacturing Company. The canal company allowed Hurd to build a flume, from the end of this canal to his own canal, along the Concord River. The completed flume carried twenty-five cubic feet of water per second beneath Central Street and on to Hurd's property. A few years later, he purchased his second mill power, which he drew directly from the lower Pawtucket Canal, just above the final locks. He thus had mill powers from both the upper and lower level of the canal system.<sup>76</sup>

Hurd was not the only one to cause troubles for Boott, over his dam construction. The temporary dam at the falls infuriated local fisherman, because it blocked the annual fish runs in the river. In the fall of 1825, Kirk Boott advertised a one hundred dollar reward for information leading to the conviction of the persons who did "maliciously tear up a part of the dam in Merrimack River, at the head

of Pawtucket Falls." He was still advertising in the Chelmsford Phenix in 1826, and in the Merrimack Journal in 1827, apparently to no avail.<sup>77</sup>

Work on a new dam began in earnest in 1826. The old Bowers' mill wing dam was apparently left in place, during the early stages of construction. It ran upstream toward the Great Rock, a huge natural anchorage at the edge of the main channel. From this massive stone formation, workers built their dam in a roughly diagonal path to the western bank. The dam followed rock ledges and projections at the head of the falls. Heavy timber cribbing and stone fill provided a solid foundation for the structure. Although the dam was not really finished, expenditures dropped from \$4,164.29 in 1827, to \$249 33 in 1829. Construction commenced again on a large scale in 1830, with some changes in the design.<sup>78</sup>

Existing records for thirty-seven of the men who worked on the dam in 1826 give some idea of the daily wages of both skilled construction workers and common laborers on Locks and Canals projects in this period. Wages for nine carpenters ranged from \$1.33 to \$2.00 per day, with most receiving \$1.50. Only one man was listed as a stone layer; he got \$1.17 per day, but was probably only semi-skilled. Locks and Canals paid three drillers \$1.16 a day and one driller \$1.25. The other nineteen men had no listed specialty. Six must have had some skill or performed some particularly hazardous work, because they were paid from \$1.16 to \$1.50 a day. One worker, paid a mere \$.66 a day, was either a youth, an

apprentice, or a handicapped man. The remaining twelve laborers earned between \$1.00 and \$1.08 for a day's toil. Men who had their own team of oxen were the highest paid of all; thanks to the value of their animals, each of the four teamsters got \$3.00 a day.<sup>79</sup>

While work on the dam progressed in 1826, the new industrial community became an incorporated town in the Commonwealth of Massachusetts. Nathan Appleton left this account of how the town got its name:

I met Mr. Boott one day, when he said to me that the committee of the Legislative were ready to report the bill. It only remained to fill the blank with the name. He said he considered the question narrowed down to two, Lowell or Derby. I said to him. "Then Lowell by all means", and Lowell it was.<sup>80</sup>

The town of Lowell had a population of 2,600 in 1826, a phenomenal growth from the 1821 estimate of 400. Already lines of boarding houses ran down Dutton and Worthern Streets from the mills of the Merrimack Manufacturing Company. Skilled workers' housing was also appearing in that area, and the new mills and corporate housing of the Hamilton Manufacturing Company were nearing completion. Following the plans of 1824, workers were finishing the canal from the Swamp Locks on a line parallel with the lower level Pawtucket. It would power the Hamilton Mills and be named the Hamilton Canal.<sup>81</sup>

Kirk Boott and the directors of Locks and Canals were ready to sell other mill sites and more water power. The island created between the Hamilton Canal and the lower level Pawtucket had room for additional

mills, and there were still plans for expansion of the canal system. In 1827, the owners of the Hamilton Manufacturing Company purchased two mill sites adjoining their property and two mill powers. The price was four dollars per spindle or \$14,336 per mill power.<sup>82</sup>

The financial success of the Merrimack Manufacturing Company and the high public confidence in the Hamilton Manufacturing Company were excellent advertisements for the water power system of the Proprietors of Locks and Canals. Lowell, by 1827, was rapidly becoming an internationally famous manufacturing center because of its paternalistic social regulation and its efficient textile factories. The early water-powered mills were not much different from those in England, but the vast amount of power available from the Merrimack River was astounding to British hydraulic engineers. The fame of the town and its factories helped to bring more investment in industrial expansion.

The Proprietors of Locks and Canals shared their practical experience in hydraulic engineering with new purchasers of water power and offered advice on the problems of power transmission throughout a mill. Within one of the early brick factory buildings, the production and transmission of mechanical power followed established English patterns closely. Secrecy was an important issue in the printing and dyeing operations, but not in the hydraulic work of Locks and Canals, at this time. Ithamar A. Beard ran a series of tests on the power used to drive machinery in the Hamilton mill No. 2 in 1830. He published

his observations three years later in the Journal of the Franklin Institute,<sup>83</sup> the best-known American technical journal of the period. Although Paul Moody had, by then, made some of the tested equipment obsolete, the publication of Beard's comprehensive study reflects both a willingness to share information and a desire for engineering recognition.

The Hamilton mill tested by Beard was the standard size built in Lowell, up to that time: "155 feet four inches long, by forty four feet four inches wide" with a basement, three stories, and a finished attic. The basement contained the water wheels and also the furnaces which heated the mill. On the first floor above were the carding machines and other equipment to prepare cotton for spinning. The spinning machinery was on the second floor and the power looms on the third. The attic story contained the warping and dressing machines which supplied warps for the weaving process.<sup>84</sup>

The mill made coarse cotton drillings from number 14 yarn. The total number of spindles was above that previously found in mills of this size.

The quantity of machinery is, two willows, two picking machines, forty three breaker, forty eight finishing cards, eight drawing frames, one Taunton speeder, twelve double speeders, thirty six warp, and thirty one filling, spinning frames with sixty four spindles each 4288 spindles; 144 looms nine warping and twelve dressing frames.<sup>85</sup>

The mill had three high breast wheels located in the heated basement where ice formation was unlikely. The head or fall of the water was thirteen feet, a height which meant the tops of the thirteen foot water wheels were approximately even with the level of water in the flumes under optimal conditions. Each of the three water wheels had buckets fourteen feet long, "equal in all to forty-two feet lengths of buckets." Adjustable gates released water into the buckets and allowed operation of the wheels even if the head were to drop up to three feet during low water conditions. This is the one great advantage of the high breast wheel over the overshot wheel, for which the head must always be higher than the top of the wheel.

The wheels are such as are denominated breast wheels. There are three sets of gates for letting the water on to the wheels, the upper gates are one foot, the second two, and the third three feet below the tops of the wheels. The gates draw horizontally, and the water flows through mouth pieces, with openings of the length of the buckets, and three inches in width, giving the water a proper direction to strike the bottoms of the buckets.

The wheels are ventilated by small wooden spouts, passing from the bottoms of the buckets to the opposite side of the wheel, so that no air can be confined within the buckets to prevent their filling with water. The water wheels, at working velocity, make 6.1 revolutions per minute, equal to 4.15 feet per second, velocity of the circumference of the wheels.<sup>86</sup>

Gearing linked each water wheel to a single horizontal shaft which then transmitted power to four vertical shafts.

On the periphery of each wheel is a spur gear, composed of sixteen segments of twelve teeth each, equal to 192 teeth. This drives a spur gear with fifty-three teeth, on a horizontal shaft in the basement story, which makes 22.1 revolutions per minute.

On the same horizontal shaft, a bevel gear, with 49 teeth, drives a bevel gear with thirty-four teeth, on each of four upright shafts, which make 31.85 revolutions per minute.<sup>87</sup>

The revolving vertical shafts went up through the mill while sets of bevel gears on each floor powered horizontal main drum shafts. Belts and pulleys connected the main drums to machinery or to counter drum shafts which drove other machines. Two sets of picking machinery (in separate buildings because of fire hazard) were "driven by a shaft geared from the horizontal shaft in the basement story."

Beard tested the power used in each room of the mill by measuring the water discharged and also by measuring shaft power with a dynamometer. For the series of tests to determine these separate power expenditures, only 3,840 spindles and 130 looms were in operation in the weaving and spinning rooms. Beard found the following average proportional powers:

*Main gear and drums	.14323
Machinery in carding room	.14817
Machinery in spinning room	.53886
Machinery in weaving room	.11272
Machinery in dressing room	.05702
	<u>1.00000</u>

\*Water wheels, gearing, and shafting alone

He determined the quantity of water expended in driving each room by measuring the discharge with only that room running, then deducting the measured discharge for running only the water wheels, gearing, and shafting. When all the separate expenditures were added up, the total was short of the quantity discharged per second when the whole mill was running. The difference was apparently caused by the greater friction losses in power transmission under a full load.

Over a twelve day period, the mill used an average flow of 88.70 cubic feet per second while in operation.<sup>88</sup> This is above the flow guaranteed for one mill power and represents a large amount of surplus water power. In 1831, the Proprietors of Locks and Canals began charging \$2.50 per spindle per year for extra or surplus power required by the mills because of increases in the number of machines and their speed of operation.<sup>89</sup>

During the last series of tests, Beard measured the discharge at 96.34 cubic feet per second. Using the formula for power, he multiplied this flow rate by 62.5 pounds per cubic foot (the density of water) and by the head of thirteen feet. The product was 78,276 foot-pounds per second, the theoretical power of that flow over the thirteen foot fall. Beard then measured with the dynamometer the "effect produced by the water acting to drive the machinery or gear." His empirical figure for the actual power produced was 47,350 foot-pounds per second. Dividing the measured by the theoretical power, he got .6049 as the

"ratio of effect to power expended." This was a reasonable efficiency for the wheels of a large textile mill in normal operation.<sup>90</sup>

With ample water power available and a record of both high profits and remarkable production in Lowell mills, industrial growth was almost assured. After the Hamilton Manufacturing Company bought their two additional mill powers in 1827, another prospective buyer approached the Proprietors of Locks and Canals. For some reason, the directors chose not to sell their mill sites south of the Hamilton mills on the same canal. Instead, they offered Mr. Francis Cabot and his associates a location north of the machine shop between the upper level Merrimack Canal and the lower level of the Pawtucket. The Cabot family held shares in the Merrimack Manufacturing Company and Locks and Canals at this time.<sup>91</sup>

Locks and Canals built a short canal in 1828 from the Merrimack Canal to the grounds of the new enterprise, the Lowell Manufacturing Company. The canal was not much more than an extended head race, but it brought the high level water to mill sites near the lower Pawtucket. The land in this area was low and swampy, requiring much solid fill for the canal banks and the foundations of mills and housing.<sup>92</sup> The surveyor for Locks and Canals, at this time, was Joel Lewis, a young man who served as a math teacher in Lowell in 1825 and 1826 before joining the canal company. He apparently laid out the plan for the Lowell Canal and superintended its construction for Boott and Moody.<sup>93</sup>

The Lowell Canal took less than a year to finish. The original shape is unclear, but one survey of a proposed section shows a trapezoidal lower half with a vertical stone wall forming the upper half of one side and an extension of one diagonal forming the other. In soft earth, gently sloping side walls were usually required if a canal builder wanted to avoid the expense of laying vertical walls of stone. The sloping sides were usually stable in soft earth without a heavy masonry covering but with the currents in a power canal, some form of puddle (usually a mixture of clay, earth, and small stones) was necessary on the surface to avoid excessive erosion. Evidence suggests that in part of the Lowell canal, both walls were vertical, despite the expense of the stone construction.<sup>94</sup>

The Lowell Manufacturing Company was an unusual addition to the group of textile companies around the canal system. Although the firm did become involved in the production of cotton cloth to a limited extent, its primary product was carpets. An additional cotton company, known as the Appleton Manufacturing Company, bought water power in 1828, and took the formerly reserved mill sites across the Pawtucket Canal from the Machine Shop and next to the Hamilton mills. Foundations were already in place, probably because of the Merrimack Manufacturing Company's early plans to build additional mills at that location.<sup>95</sup>

Locks and Canals usually built the mills for each new company. The canals carried bricks, timber, and stone to a point at or near the

mill sites. For the Appleton mills, transportation was particularly easy; the Hamilton Canal branched from the Pawtucket right at the Swamp Locks basin and ran by the mill sites. Once these mills were standing, Paul Moody tried a radical departure from the usual method of power transmission in a factory.

In the Appleton mills, Moody abandoned the heavy bevel gears and vertical shafts which took the power to each floor. Mechanical friction losses were high with the metal gearing, and it was both expensive and difficult to fabricate proper gears. Instead, Moody used huge leather belts running from the main shaft in the cellar to the horizontal shafting on the first and third floors. Smaller belts ran from these shafts to power counter shafts and machines on the same floor and on the one directly above. The idea was known in England, but became much more widespread in America, and was considered one of the distinctive features of the American factory system by the 1840's.<sup>96</sup> Samuel Batchelder, a manufacturer and early industrial historian, wrote of Moody's achievement:

The use of leather belts instead of iron gearing for transmitting motion to the main shafting of a mill, was introduced by Mr. Paul Moody, at Lowell, in 1828. Though not to be called an invention, this proved to be a very important improvement, and was entirely original in its application to the transmission of fifty or an hundred horsepower by a single belt, and has been very generally adopted in the mills in New England.<sup>97</sup>

Even before Moody had finished the Appleton mills, his company had already begun another canal to the mill sites northwest of the Merrimack mills and print works. Optimism among the directors of

Locks and Canals was high, for no definite sales of water power and land had yet taken place. The first excavations where the canal was to leave the Swamp Locks served a dual purpose. Earth removed for the canal became part of the fill for the mill yard and housing area of the Lowell Manufacturing Company.<sup>98</sup>

Deacon Rand came back to Lowell to excavate part of the Western Canal. He built a railway track from the canal site to the grounds of the carpet company, in order to haul the heavy loads of earth needed in the low area. This was in 1829, just three years after the introduction of the railway in the United States at the nearby Quincy Quarry. William Worthern described the one in Lowell as "a track of wooden stringers with a strap rail." Peter Lawson, a carpet pattern designer, remembered that "the cars were drawn by horses, under direction of Hugh Cummiskey, contractor."<sup>99</sup>

The Western Canal, sometimes called the Suffolk Canal, was difficult to build because of the same type of rock ledges that had held up excavation of the Merrimack Canal. Almost a mile in length but much narrower than the Pawtucket that fed it, the new power canal opened on Thanksgiving Day, 1831. Work on the canal and an extension of it, known as the Lawrence Canal, continued for two more years. In all, the Proprietors of Locks and Canals spent just over \$70,000 for the Western Canal.<sup>100</sup>

The Western Canal, like the Pawtucket, had both an upper and lower level. Three cotton textile companies, all incorporated in 1830, built mills on the Western or its extension. The Suffolk and Tremont Manufacturing Companies, on opposite sides of the upper level canal, began production in 1832. After the canal ran between the two mill yards at the upper level, it dropped to the lower level over a dam completed in 1832. Head races led from the upper canal into the wheel pits of both companies and tail races led back to the canal below the dam. Each company purchased an equal amount of power from Locks and Canals:  $4\frac{1}{3}$  mill powers each in 1832.<sup>101</sup>

The Lawrence Manufacturing Company bought mill sites along the Merrimack River. The Lawrence Canal was really a perpendicular extension of the lower Western. It paralleled the river bank and supplied power to the line of Lawrence mills. Boats and rafts reached the mills by means of transportation locks at the dam between the upper and lower Western. Another dam spilled excess water not needed in the Lawrence Canal back into the river.<sup>102</sup>

The Lawrence Manufacturing Company bought six mill powers in 1833. This was more than either upper level mill on the Western, because the discharge of both eventually reached the Lawrence Canal and was available for power production. The Lawrence actually had access to more water than needed to generate six mill powers under normal river conditions. However, when the river was high, the water level in the Lawrence tail races could impede the revolutions of the breast wheels. Under these

"backwater conditions," the Lawrence mills needed all the water they could get to drive their wheels.<sup>103</sup>

The Western Canal construction coincided with extensive work on the Pawtucket Dam. In 1830, Locks and Canals completed the dam at a height of thirty feet on the company scale. Abandoning the old line of the Bowers Mill dam, the structure crossed upstream, from the eastern bank to the Great Rock. From there, it extended across the head of the falls on the timber crib work built from 1826 to 1828. Two courses of granite headers laid without cement capped the dam in 1830, but in 1833, Locks and Canals again raised the dam by adding two more courses of granite headers. In addition, the company added flashboards to the top of the dam to hold the water at an even higher level.<sup>104</sup>

Although Locks and Canals included a fishway in their dam to avoid complaints from river fishermen, the unprecedented height of the dam created different problems. With two foot flashboards in place from late spring until winter, the effective top of the dam was four feet over the thirty foot mark on the Locks and Canals scale. Water backed up, or ponded, from the dam at Pawtucket Falls to Cromwell's Falls in New Hampshire.<sup>105</sup> The rise in water level at Nashua, New Hampshire, at the mouth of the Nashua River, was enough to cause difficulties for the Jackson Company.

The Jackson mills had water wheels in fixed positions, so that water in the tail races did not normally interfere with the rotation of the wheels. Water in the wheel buckets fell off near the bottom point of a revolution and exited smoothly back to the river. When the Proprietors of Locks and Canals began raising their dam above the 1830 height, the owners of the lower factories on the Nashua River faced the threat of higher water in the river, and hence, higher levels in their tailraces.<sup>106</sup> Backwater was the greatest problem for water wheels and the Lowell manufacturers seemed willing to flood the wheel pits of mills upstream.

At one heated point in the dispute, the owner of the Jackson Company complained bitterly that the dam was "a great and vexatious nuisance and a trespass causing complaints among their operations, rendering their works uncertain and irregular, impeding their wheels and sometimes stopping them, and thereby, making the proceeds of their mills less in amount and value and giving a bad reputation of their establishment." He went on to threaten the Proprietors of Locks and Canals that he would not only hold them responsible for all damages and losses, but would also feel free "to abate the nuisance and free said main passage of the river at Pawtucket Falls from the dam there raised and from all obstructions whatever--"<sup>107</sup>

The series of letters from the Jackson Company to Locks and Canals had no real effect on plans in Lowell. The canal company and the textile corporations saw too many benefits in the new dam to give

in to the demands from New Hampshire. The extra two feet of height produced by the flashboards increased the storage capacity above the dam by almost ninety four million cubic feet. That extra storage was enough water to provide 83.6 mill powers in the two levels of the Lowell canal system, if consumed over a twelve hour period.<sup>108</sup> The reservoir created by the dam helped maintain an adequate supply of water for the Lowell mills, even in brief dry spells.

The Proprietors of Locks and Canals defended their rights to the dam by denying that they were blocking a navigable passage. They argued that the falls were impassable, with or without a dam, and that their mill privileges gave them the power to build a dam for manufacturing purposes. They accused the Jackson Company of exaggerating the problem in Nashua,<sup>109</sup> but were much more conciliatory to the owners of the Middlesex Canal, who also complained about the dam.

The Wickasee Locks of the Middlesex Canal were four miles upstream of the dam. They had made Wickasee Falls passable and had been a source of revenue for the transportation company. When the Proprietors of Locks and Canals raised the level of water in the river behind their dam, the Wickasee falls were no longer a serious obstacle and the locks were submerged. The Middlesex Canal Company, having lost the tolls usually collected at the locks, insisted on a cash settlement. Since the Middlesex Canal carried both raw materials and finished products for the Lowell corporations, Locks and Canals was willing to submit the matter of the locks to arbitration. The proprietors eventually paid

the Middlesex Canal Company a settlement of \$11,750.<sup>110</sup>

Raising the dam, in the early 1830's, also presented a threat to the Guard Locks on the Pawtucket Canal. A freshet in 1831 nearly washed out the old sluice gates at the Guard Locks, probably because the more effective dam increased the height of the flood waters. Locks and Canals rebuilt the sluice gates, walls, and abutments in 1832, just before additional construction on the dam. Each gate was made in four parts to facilitate lifting by hand.<sup>111</sup>

Paul Moody, who had helped to shore up the guard sluices during the spring freshet of 1831, did not live to see them rebuilt. The great mechanical engineer became ill in early July and died three days later, at the age of fifty-two. His death stunned the people of Lowell as well as the absentee owners of the textile corporations. In the Reverend Edson's funeral sermon, Moody's skills and technical achievements received well-deserved attention:

His death produced a greater sensation than any other single event that has transpired in this town...He died in the full strength of mind. He was a man of extraordinary intellect. He was one of those who identified himself with the rise, growth, and prosperity of this flourishing village. He was one of the two who first set foot upon the soil with the slightest idea of what it might become. From the earliest active measures, he has sustained a conspicuous part of this enterprise; and it should be remembered, the place which he had held in this concern, he has sustained by the uncommon strength and acuteness of his practical talents.<sup>115</sup>

Joel Lewis, Moody's principal surveyor and engineering assistant, supervised the engineering projects already underway or scheduled at the time of the chief engineer's death. Moody had trained this able young

man and had already given him large responsibilities.<sup>114</sup> The Proprietors of Locks and Canals hired another young engineer to help Lewis in July 1831; Uriah Boyden joined the company as an aspiring hydraulic specialist and was soon making studies of the Merrimack River, while Lewis was finishing the dam.<sup>115</sup>

In the spring of 1834, the Proprietors of Locks and Canals hired another engineer, Major George Whistler. A West Point graduate and an experienced railroad engineer, Whistler came to Lowell to build locomotives in the machine shop. Patrick Tracy Jackson and his associates had already begun the construction of a railroad from Lowell to Boston. They wanted Whistler to make locomotives for use on the Boston and Lowell, and on other lines in the growing nation. George Brownell, one of Moody's foremen, took over the production of textile machinery in the shop, and Joel Lewis continued to supervise work on the water power system.<sup>116</sup>

This division of responsibilities capitalized on the particular expertise of each man, but within a few months, Joel Lewis was dead. Instead of elevating Uriah Boyden to a position as the sole hydraulic engineer, the proprietors took Whistler's advice and hired James B. Francis, a nineteen year old English engineer who had worked with Whistler on the Stonington Railroad in Connecticut.<sup>117</sup> The choice proved to be an excellent one, for Francis soon became an extremely valuable hydraulic engineer. In time, both he and Boyden earned international reputations in the field of hydraulics.

The first major task for James Francis in Lowell was to finish the basic canal system planned in the 1820's. The Merrimack, Hamilton, Lowell, Western, and Lawrence Canals were operating as power canals, but most of the water flowing down the lower level Pawtucket spilled over the final dam into the Concord River and wasted seventeen feet of head. All the discharge from the machine shop and the mills of the Lowell, Hamilton, and Appleton Manufacturing Companies went into the Pawtucket again, after losing only thirteen of the thirty feet of elevation in the system. A major canal on the lower level fed by the Pawtucket was the one piece left to complete the early plan.

Since 1828, the lower level Pawtucket had provided one mill power; first to Thomas Hurd's mill by the lower locks, then to the Middlesex Manufacturing Company which bought up his old property along the Concord in 1831.<sup>118</sup> This large woolen company became the only corporation in Lowell to draw power from both the Merrimack River, via the Pawtucket Canal, and the Concord River. The demands of the Middlesex mills for water from the lower Pawtucket were very slight compared to the available flow in 1834.

Since 1824, Locks and Canals had planned a canal to supply water power to mill sites along the Merrimack and Concord rivers from the Merrimack mills to the Lower Locks of the Pawtucket. In the fall of 1834, the sale of at least four mill sites seemed assured, and the directors accepted a "plan locating nine mills on the lower level and

the canal to supply them with water." Kirk Boott ordered construction to begin by the following spring.<sup>119</sup>

With James Francis as hydraulic engineer and construction supervisor, work on the Eastern Canal progressed very rapidly. From the lower locks of the Pawtucket, the path of the canal was a straight line almost parallel to the Concord River. As the canal approached the Merrimack, it turned ninety degrees to the northwest and paralleled that river almost to the Merrimack mill yards. The overall distance was nineteen hundred feet, and the canal had a greater capacity than any of the other branch canals. Although work on the Eastern continued for another year, Francis managed to power the first mill of the Boott Manufacturing Company in July of 1836. Total expenditures on the canal by July 1837 amounted to \$35,773.88.<sup>120</sup>

The Eastern Canal made further development possible near the junction of the Concord and Merrimack Rivers. It was the last power canal built in Lowell to use the Pawtucket Canal as its feeder, and it completed the plans of Paul Moody, Kirk Boott, and the other early designers of the canal system. The power available from the system in 1836 was greater than Moody had estimated in 1823, but a period of enormous industrial growth in Lowell was just beginning.

The first stage of canal construction was essentially complete in 1836. The two level system seemed to work well in most seasons, and there were still mill sites available for additional companies. Lowell had become a famous city, an industrial center on the rise. The

community had grown up around the mills, the canals, and the vacant land still held by the Proprietors of Locks and Canals. Such development had produced a distorted pattern of streets and buildings, but had done little to deter the influx of workers and families. In most ways, the community was both a social and industrial success. Yet, the time had come to look critically at the results of rapid growth and at the problems involved in further urban and industrial development.

FOOTNOTES - CHAPTER III

1

John Coolidge, Mill and Mansion (New York, 1967), p. 23.

2

Richard Wade, Urban Frontier (Cambridge, 1959), p. 4, 24, 27-29.

3

Conclusions based on physical examination of the site and map analysis.

4

Locks and Canals, Directors' Records (26 December 1821).

5

See Ibid.; and Nathan Appleton Introduction of the Power Loom, and Origin of Lowell (Lowell, 1858), pp. 23-24.

6

See Alfred Gilman, "Sketch of the Life of Kirk Boott," CORHA, II, p. 3; James Francis, "Kirk Boott and His Experience in the British Army," CORHA, III, p. 326; and James Montgomery, The Cotton Manufacture of the United States Compared and Contrasted with that of Great Britain (Glasgow, 1840), pp. 163-164 n.

7

Peter M. Molloy, "Technical Education in the New Republic: West Point as America's Polytechnique 1802-1833," (Ph.D. dissertation, Brown University, 1975), chapter 3. Also, for a discussion of Boott's architectural ability, see Coolidge, Mill and Mansion, p. 190n.

8

Appleton, Introduction of the Power Loom, p. 18.

9

William R. Bagnall, "Paul Moody," CORHA, III, pp. 59-69.

10

Ibid., pp. 67-68.

11

Nathan Appleton, MS. dated 15 April and later incorrectly marked as 1824. From the context it must be 1823. In the Massachusetts Historical Society.

12

George Gibb, The Saco-Lowell Shops: Textile Machinery Building in New England 1813-1949 (Cambridge, 1950), p. 66.

13

Locks and Canals, Directors' Records (26 December 1821).

14

Nathan Appleton, Introduction of the Power Loom, p. 23.

15

See Laommi Baldwin, "Report, Survey, and Estimates of the Water Power and Manufacturing Privileges Owned by the Sewall's Falls Locks and Canal Corporation, Concord, NH on the East Side of the Merrimack River" (Concord, NH, 1839), pp. 6-14; and Julian C. Hinds, "Canals, Flumes, Covered Conduits, Tunnels, and Pipe Lines" in Calvin V. Davis, ed., Handbook of Applied Hydraulics (New York, 1942), pp. 458, 463.

16

Ibid.

17

Ideas drawn partly from the Baldwin "Report" and partly from my own calculations.

18

Baldwin, "Report," pp. 13-14 examines the ice problem, but because of the peculiarities of the specific area he is evaluating, he still prefers a trapezoidal shape.

19

These conclusions are my own: No evidence has come to light which reveals the precise reasons for the rectangular section in Lowell canals.

20

See Merrimack Manufacturing Co. MSS., vol. 14 (Journal) and vol. 28 (Ledger); Charles Cowley, History of Lowell (Lowell, 1868), pp. 44-45; Dr. John O. Green, "Autobiography," CORHA, III, pp. 233-234.

21

See Green, "Autobiography," pp. 233-234; and a newspaper account of Dr. Green's speech on Kirk Boott. The barn-barracks were near the site of the Lowell Gas Works on the old Fletcher Farm. The location was very close to the Pawtucket Canal.

- 22  
Green, "Autobiography," pp. 233-234.
- 23  
J.G. Kittredge, "Recollections of Early Times in Lowell," Vox Populi  
(Lowell, 14 September 1873).
- 24  
Cowley, History of Lowell, pp. 44-45.
- 25  
See Locks and Canals, Pawtucket Locks and Canals (Lowell Technological  
Institute Collection), Canal Sections, 1921, and "A Plan of the Land on the  
South Side of the Pawtucket Canal Belonging to the Merrimack Mfg. Co.,"  
(January, 1824). The canal system is drained periodically for repairs. When  
empty, the rough sides and bottom are obvious in the present Pawtucket Canal.  
The Merrimack Canal is even more irregular.
- 26  
Green, "Autobiography," pp. 234-235.
- 27  
See Locks and Canals, Directors' Records, (26 December 1821); and  
Handbook for the Visitor to Lowell (Boston, 1848), p. 25.
- 28  
James B. Francis, Lowell Hydraulic Experiments (Boston, 1855), p. 104.
- 29  
See Locks and Canals, map of "Chelmsford, June, 1825" by George  
R. Baldwin; and Francis' "Records," H, for a historical sketch written in

October 1870.

30

See Locks and Canals, "A Plan of the Land on the South Side of the Pawtucket Canal . . ." (January 1824).

31

See J.G. Kittredge, "Another Chapter of Recollections," Vox Populi (Lowell, 19 November 1872); and his recollections in Alfred Gilman, "History of Central Bridge," CORHA, II, p. 297.

32

Kittredge, "Another Chapter,"

33

Ibid.

34

See Francis, Lowell Hydraulic Experiments (1855), p. 104; Kittredge recollections in Gilman, "History of Central Bridge," p. 297; and Locks and Canals, Charter of 1792, in Directors' Records.

35

Kittredge, "Another Chapter."

36

See Ibid.; Merrimack Mfg. Co. MSS, vol. 14 (Journal) and vol. 28 (Ledger); and Alfred Gilman, "History of Central Bridge," pp. 296-299.

37

See Green, "Autobiography," pp. 233-235; Locks and Canals, Book of Indentures, Merrimack Mfg. Co. (1826)

38

See William Worthen, "Life and Works of James B. Francis," CORHA, IV, p. 234; and Dwight Porter, "Water Power of the Merrimac River and of the Rivers of the Eastern Massachusetts Between the Merrimac and the Blackstone" (unpublished study in possession of Locks and Canals, 1889), p. 23.

39

See extracts from Kirk Boott's diary in Locks and Canals, Francis' "Records," H; Appleton, Introduction of the Power Loom, p. 24; and Merrimack Mfg. Co. MSS, vol. 14 (Journal) and vol. 28 (Ledger).

40

Boott's dairy quoted in William R. Bagnall, "Sketches of Manufacturing and Textile Establishments in New York City and of Textile Establishments in the Eastern States" (published only in part - this section in MSS), p. 2157. Boott's long in the possession of the Lowell Historical Society and unpublished by family request, has disappeared. Only a few scattered quotations survive.

41

Locks and Canals (Lowell Technological Institute Collection), drawings of Merrimack Mill signed by Patrick Tracy Jackson, 1822. The wheel dimension is planned as (but not built) twenty-eight feet. All dimensions recorded after completion state thirty feet in diameter, matching the fall selected

by Moody. John Duinmer actually constructed it and probably all of the early breast wheels in Lowell; "Discussion," American Machinist (27 June 1895), p. 510. I am indebted to Larry Lankton for his analysis of the breast wheels in Lowell.

42

Kirk Boott, quoted in Bagnall, "Sketches of Manufacturing and Textile Establishments," pp. 2157-2162, and in Locks and Canals, Francis' "Records," H.

43

See Nathan Appleton, Introduction of the Power Loom, p. 23; Locks and Canals (Lowell Technological Institute Collection), drawing of Merrimack New Mill No. 1, July 9, 1853, with new plan over the old; and Bagnall, "Sketches of Manufacturing and Textile Establishments," p. 2025.

44

Nathan Appleton, MS. dated 15 April, written in 1823. See Footnote 11.

45

Ibid.

46

Ibid.

47

See Boston Mfg. Co., Directors' Records, March 19, 1822; and Merrimack Mfg. Co., Directors' Records, December 22, 1821, and list of shareholders in both companies, February 1822.

48

Merrimack Mfg. Co., Directors Records, Report to Proprietors August 9, 1823.

49

Ibid.

50

See Locks and Canals, "Plan of the Buildings and Land Belonging to the Merrimack and Hamilton Manufacturing Companies and the Proprietors of Locks and Canals on the Merrimack River," Jn. G. Hales, surveyor, 1827; Locks and Canals, Francis' Records, A, November 27, 1843 for a description of a machine shop water wheel; and Bagnall, "Sketches of Manufacturing and Textile Establishments," p. 2154.

51

Ibid.

52

Appleton, MS., dated only April 15.

53

See two different plans with the same title and date: Locks and Canals, "A Plan of the Land on the South Side of the Pawtucket Canal . . ."

54

Merrimack Mfg. Co., Directors' Records, May 19, 1824.

55

The plan includes the same intention to narrow the Pawtucket Canal as the other 1824 plans mentioned above. This work was underway in 1825 and

essentially complete by 1826. Locks and Canals, filed under shelf 118, drawing 272.

56

See Locks and Canals.

and an untitled plan of January, 1826, showing projected Western and Lawrence Canals, filed under Shelf 123, drawing 2827. William Worthen, whose father ran the first Merrimack Mills and who worked as a surveyor for Locks and Canals, said that plans for the early system were completed soon after the completion of the Merrimack Canal. William Worthen, "Life and Works of James Francis," p. 234.

57

Merrimack Mfg. Co., Directors' Records, October 19, 1824.

58

Ibid.

59

See Ibid., November 23, 1824 and Caroline Ware, The Early New England Cotton Manufacture (New York, 1966), pp. 320-321. Ware has compiled a list of shareholders in more than one Lowell company.

60

Patrick Tracy Jackson to Rufus King, October 6, 1824, Lee Family Papers, "B" Letters of P.T.J., Massachusetts Historical Society.

61

Merrimack Mfg. Co., Directors' Records, February 28, 1825.

62

See Locks and Canals and Merrimack Mfg. Co., Directors' Records, 1822-1825, passim. Once the Merrimack Mfg. Co. acquired a controlling interest in Locks and Canals, it easily picked up the rest of the stock.

63

Locks and Canals, Directors' Records, February 12 and 28, 1825. The stock in Locks and Canals had been increased from 500 to 600 shares since the takeover.

64

Table from Gibb, The Saco-Lowell Shops, p. 69. Derived from data provided by Bagnall, "Sketches of Manufacturing and Textile Establishments," pp. 2072-2075. Locks and Canals, "Book of Indentures," shows an agreement for seven mill powers, up from six, and an additional payment in 1826.

65

See Locks and Canals, "Book of Indentures," form of lease for Hamilton Mfg. Co., and Locks and Canals (Baker Library Collection), Hiram F. Mills, "Historical Sketch" (1907), pp. 1-2.

66

Handbook for the Visitor to Lowell (Boston, 1848), p. 25.

67

Mills, "Historical Sketch," pp. 1-2.

68

Appleton, Introduction of the Power Loom, p. 28. The figure of seventy

per cent efficiency was derived by using the sixty horsepower figure and solving for efficiency. It seems close to the best results of Francis' many experiments on breast wheels, recorded in Locks and Canals, Francis' "Records," A. However, it is above the average efficiency found by Ithamar A. Beard in the Hamilton mills in 1832. Beard is discussed later in this chapter.

69

See Handbook for the Visitor to Lowell, p. 25; and Locks and Canals, "Book of Indentures."

70

See Locks and Canals, "Book of Indentures," and Directors' Records, May 3, 1826.

71

Locks and Canals, "Book of Indentures," Amount of land varied some, but four acres seems the average. Locks and Canals drawings at Lowell Technological Institute show mill construction, raceway, and penstock work by Locks and Canals.

72

See Locks and Canals, Francis' "Records," H, dam history; and Merrimack Mfg. Co., Directors' Records, W. Dutton to K. Boott, October 25, 1824.

73

Merrimack Mfg. Co., Directors' Records, October 23, 1824.

74

See Locks and Canals, "Plans and Deeds of some of the Land Acquired by P.L. & C. 1792 to 1928," nos. 58-60; and Merrimack Mfg. Co., Directors' Records, June 1, 1825.

75

Locks and Canals Directors' Records, March 17, 1826.

76

See Locks and Canals, Directors' Records, April 1, 1826; "Plan of the Privileges, Factories and Land in Lowell Belonging to Thomas Hurd," 1829; sketch by U.A. Boyden in leather "Records" volume, before 1833; "Book of Indentures," Hurd indentures, June 23, 1826 and October 1, 1828.

77

See Chelmsford Phenix, October 7, 1825 to February 24, 1826 and Merrimack Journal, March 24, 1826, June 3, 1827.

78

See Locks and Canals, Francis' "Records," H; Locks and Canals (Baker Library Collection), Francis' rough draft of history of the dam, 1876; and Locks and Canals, "Sketch of Pawtucket Dam," March, 1923 (with historical development).

79

Locks and Canals (Baker Library Collection), RC-1, July-October, 1826.

80

Appleton, Introduction of the Power Loom, pp. 32-33.

81

Ibid.

82

Locks and Canals, Directors' Records, April 23, 1827, May 22, 1827, June 9, 1827, and August 4, 1827.

83

Ithamar A. Beard, "Practical Observations on the power expended in driving the machinery of a Cotton Manufactory at Lowell," Journal of the Franklin Institute 11 (1 January 1833). See also J.B. Francis' observations on these tests in his "Records," A.

84

Beard, "Practical Observations," p. 6.

85

Ibid.

86

Ibid., pp. 6-7.

87

Ibid., p. 7.

88

Ibid., pp. 6-13.

89

Locks and Canals, Directors' Records, September 5, 1831.

90

Beard, "Practical Observations," pp. 13-15. Beard also ran tests on partial gate openings.

91

Locks and Canals, Directors' Records, December 14, 1827.

92

Peter Lawson to City Council, February 29, 1876, in CORHA, VI, pp. 73-74. He came to Lowell in 1829 to work for the Lowell Manufacturing Co.

93

Joshua Merrill, "Reminiscences of Joel Lewis," CORHA, I, p. 63.

94

Locks and Canals (Baker Library Collection), surveys and construction agreement of January 18, 1828, NB-1, NA-1.

95

See Locks and Canals, "Book of Indentures," and Directors' Records, April 23, 1827.

96

Samuel Batchelder, Introduction and Early Progress of the Cotton Manufacture in the United States (Boston, 1863), p. 88; Montgomery, James A Practical Detail of the Cotton Manufacture of the United States (Glasgow, Scotland, 1840), p. 19-22.

97

Samuel Batchelder, Introduction and Early Progress of the Cotton Manufacture in the United States (Boston, 1863), p. 88.

98

Lawson to City Council, pp. 73-74.

99

See Ibid.; and Worthen, "Life and Works of James B. Francis," pp. 228-229.

100

See Locks and Canals (Baker Library Collection) Western Canal agreements and diagrams, 1830-1831, NA-1, Nb-2; Costs, FC-1, Folio 131 and 247; Locks and Canals, "Plan of the Town of Lowell and Belvedere Village," by Benjamin Mather, 1832.

101

See Locks and Canals, Book of Indentures, and untitled plan of dam (Hickey Hall dam) filed under Shelf 117, drawing 334.

102

See Ibid. and Beyden, "Book of Plans, 'A.'"

103

See Locks and Canals, Book of Indentures, and Directors' Records, Francis' Reports of February 5, 1848, and July 28, 1881.

104

See Locks and Canals, "Sketch of Pawtucket Dam," 1923; and Francis' "Records," H; and Locks and Canals (Baker Library Collection) Francis' Report of September 21, 1864.

105

See Locks and Canals, Boydens Report on October 12, 1840 in Francis'

"Records," A, and Beyden, "Plan of a ~~Part~~ of Merrimack River Between Nashua and Lowell," March 1833.

106  
Locks and Canals, Directors' Records, series of letters from the Jackson Co., 1832-1833.

107  
Ibid. See also Laommi Baldwin's report to the Jackson Co., June 19, 1834, filed in Locks and Canals (Baker Library Collection) under PH-CIO.

108  
Beyden Report in Francis' "Records," A.

109  
See Locks and Canals, Directors' Records, and the opinion of Judge Jackson, January 15, 1833, in officer file No. 1109.

110  
Locks and Canals, Directors' Records, February 5, 1835, February 24, 1835, and March 31, 1835.

111  
See Locks and Canals, Francis' "Records," H, October 25, 1870; Worthen "Life and Works of James B. Francis," p. 236, and J.B. Francis, "Great Freshets in Merrimack River," CORHA, III, p. 255-256.

112  
Worthen, "Life and Works of James B. Francis," p. 236.

113

Quoted in Bagnall, "Paul Moody," p. 71.

114

Joshua Merrill, "Reminiscences of Joel Lewis," CORHA, I, p. 63.

See also quotations from Lewis' journal on dam construction in Francis' "Records," H, and copy of Lewis' plan for the Suffolk wheel pits in Locks and Canals, Francis' "Waste Book," 1837-1860.

115

See Locks and Canals (Baker Library Collection) file NA-1; and Locks and Canals, Francis' "Records," river survey, 1833.

116

See Gibb, Saco-Lowell Shops, pp. 84-85, 92-94; and Worthen, "Life and Works of James B. Francis," pp. 230-231.

117

Worthen, "Life and Works of James B. Francis," pp. 229-231.

118

Locks and Canals, Book of Indentures.

119

See Locks and Canals, Directors' Records, October 6, 1831 and September 20, 1834; and Locks and Canals (Baker Library Collection), FC-1, Folio 336 for dates of expenses.

120

See Locks and Canals, Book of Indentures; Locks and Canals (Baker Library Collection), FC-1 and NA-1; and Bagnall, "Sketches of Manufacturing and Textile Establishments," p. 2305.

## CHAPTER IV

The town of Lowell became a city in 1836, the same year which marked the opening of the Eastern Canal and the completion of the first phase of water power development in the growing industrial center. The population rose to 17,600, and there were job openings for hundreds of workers in the new Boott Cotton Mills. At the end of the year, the eight major textile corporations of the city had 146,128 spindles, 4667 looms, 6085 female operatives, and 1827 male employees.<sup>1</sup>

The Statistics of Lowell Manufactures for 1836 gives an annual production figure of 49,413,000 yards of cloth. Cotton consumption amounted to 15,444,000 pounds, with each pound converted into an average of 3.2 yards of cotton cloth. In all, twenty-six textile mills, two print works, and the machine shops of Locks and Canals were operating with power supplied by the Merrimack River.<sup>2</sup>

Even the national economic crisis known as the "Panic of 1837" did not arrest the development of Lowell. Although some cooperation between corporations was necessary, all of them rode out the troubled times without significant drops in production or number of employees. The directors of the Boott Cotton Mills continued their building program and increased capitalization by \$200,000 during the "Panic."<sup>3</sup> By the end of the decade, several major stockholders in Lowell Companies had demonstrated their confidence in the cotton industry by joining with friends to form another large corporation.

The Massachusetts Cotton Mills received a charter in 1839 and purchased mill sites next to the Boott property. The new cotton mills were built by Locks and Canals as part of a large contract involving land, water power, machinery, and construction:

1. To supply four mill sites comprising 11-1/2 acres of land to together with water equal to nine mill powers, 24 hours per day, at an annual perpetual rental of \$2,400 - \$84,023.
2. To procure materials for and erect four mill buildings, including gearing and such other buildings as may be wanted, but not to be responsible for delivery at any specified date - at cost.
3. To furnish machinery and tools for the same price as charged the Boott Mills. Any improvements over the Boott machinery to be installed with the consent of the Boott Mills management - \$72,500 per mill (of approximately 6,000 spindles).
4. Machinery for Mill Number One to be completed in 14 months:  
machinery for Mill Number Two to be completed in 20 months:  
machinery for Mill Number Three to be completed in 26 months:  
machinery for Mill Number Four to be completed in 32 months.
5. Payment for machinery to commence three months from date of contract and be at the rate of \$35,000 every three months.<sup>4</sup>

The Massachusetts mills drew water from the Eastern Canal and discharged through tailraces into both the Concord and Merrimack Rivers. A smaller corporation, the Prescott Manufacturing Company, moved onto an adjacent piece of Locks and Canals land in 1845 but became part of the Massachusetts Company within three years.<sup>5</sup> No new enterprises were to join the select group of manufacturers on the Locks and Canals system in the nineteenth century.

The ten textile corporations which were to dominate the social, political, and economic life of Lowell for the rest of the century were all on the canal system by 1840. Since 1822, the placement of mills and canals had highest priority in the planning of the community. Lowell existed to manufacture textiles, and the city plan reflected this fact. The power canal system spread across the landscape of the city in a pattern clearly designed for industrial development, even at the expense of urban living conditions.

Canals and mill yards cut the city into sections, preventing the formation of a practical street plan. Street grids appeared only as isolated elements juxtaposed between the radial arms of the power canals, and widely-spaced bridges over the man-made channels were the sole connections between some adjoining neighborhoods. Few streets cut through the industrial barriers that separated one district from another.<sup>6</sup>

Within a few years of the completion of the Eastern Canal, an almost solid ring of industrial development circled the heart of Lowell.<sup>7</sup> Beside the lower Pawtucket Canal stood the mills of the Hamilton, Appleton, Lowell, and Middlesex Corporations as well as the great machine shop of Locks and Canals. The Massachusetts and Boott mills were between the Eastern Canal and the river banks. Upstream along the great river were the Merrimack mills and print works and the factories of the Lawrence Corporation. Finally the Tremont and Suffolk mills flanked the Western Canal. From there to the Swamp Locks was the only significant gap in the chain of mills.

Only two through streets pierced the ring of mill yards. Merrimack Street, running east and west, and Central Street, running north and south, followed the rough direction of earlier country highways. Merrimack Street crossed the Concord River just below the Middlesex mills, then spanned the Eastern, Merrimack, and Western Canals before connecting with Pawtucket Street on the bluff above Pawtucket Falls. Central Street ran north through a residential section known as Chapel Hill and crossed the lower Pawtucket Canal between the mill yards of the Hamilton and Middlesex Corporations. It ended at Merrimack Street near the Central Bridge, formerly a ferry crossing. From the Swamp Locks to the Concord River, Central Street was the only route across the Pawtucket Canal. The Hamilton and Appleton mills formed an effective barrier to north-south traffic, forcing it east to Central Street or west, beyond the Swamp Locks, to Thorndike Street.

Already the power canals were helping to enforce a form of ethnic segregation by isolating the squalid huts of the Irish day laborers and their families. Both the Carpenter - Gothic St. Patrick's Church and the Irish shanty town known as "the Acre" were just beyond the Western Canal, conveniently separated from the heart of the city. Across that canal was "the wrong side of the tracks" in the social geography of early Lowell.<sup>8</sup>

Even if the canals affected urban development in ways that were not always beneficial, their great contribution to the economic strength of the city seemed adequate compensation in the prevailing "boom-town" philosophy of the times. The well-being of almost every Lowell resident was dependent on the financial success of the textile mills, a success which, in turn, was dependent on the efficient operation of the power canal system. The Proprietors of Locks and Canals had to keep up with the power demands of the expanding textile operations if Lowell was to continue its pattern of economic growth.

Every additional spindle in the mills meant an increase in the demand for power. There was still ample energy available from the Merrimack River, but already the canal system was showing signs of strain. It had been built very rapidly, and the flaws in its design and construction were becoming serious problems. The current in the canals, particularly in the Pawtucket Canal, which fed the whole system, was now faster than the designers had anticipated. As the mills used more water, the flow through the system increased and hydraulic efficiency began to decline.<sup>9</sup>

Water moving in a canal brushes against the sides and bottom of that channel and loses energy because of friction with those surfaces. That energy loss results in a drop in elevation or head. In other words, the water's energy of position due to its elevation is partly sacrificed because of energy losses due to friction. As a result, the water level actually drops. Friction losses increase when the water velocity, or current, increases and also when the containing surface becomes rougher.<sup>10</sup>

The Lowell canals were built in such a hurry that surface finishes were often left very rough, even jagged in rock ledge. Water flowing rapidly through the canals generated excessive friction in some sections and suffered serious head losses. It arrived at a distant mill several feet lower than it had been at the entrance of the Pawtucket Canal and therefore with less energy for the production of mechanical power. Thus, as the mills drew more water onto their wheels, the head losses produced by a greater flow rate caused the water to strike the wheels at a point lower than the engineers wished. Some head loss was unavoidable in any power canal, but the situation was becoming worse in Lowell as each year passed.<sup>11</sup>

Sharp turns in the canal system contributed to normal friction losses but also wasted additional energy by causing disruptive eddies in the moving water. The most serious problems occurred on the Eastern Canal and at the ends of the Western and Merrimack Canals. In order to create as many mill sites as possible the designers had to plan some canals which changed direction to parallel the river bank. The Eastern, for instance, branches from the Lower Pawtucket above the Lower Locks, follows the bank of the Concord River in a straight line and then turns ninety degrees to follow the bank of the Merrimack River. The extensive industrial complex of the Boott Cotton Mills would not have been possible without the turn in the canal, but head losses were a persistent side effect of the design. Smooth curves instead of sharp bends would have been beneficial to the operation of the system, though admittedly expensive and difficult to construct.

The design of tailraces was another cause of head loss in the system. Some mills on the upper level discharged water into the lower level in an inefficient manner. After passing from the wheel pits, water flowed through tailraces, usually underground, and entered the lower canal at a right angle to its direction of flow. This rush of water from the side of the canal disrupted the flow, created turbulence, and became a form of hydraulic barrier. The resulting energy loss caused a drop in the level of the canal and less power for mills downstream.<sup>12</sup>

Mills on the lower level of the canal system were at a definite disadvantage. They were supposed to receive water with seventeen feet of head for power generation, but for a number of reasons, were frequently short changed. The Boott mills had the worst location and the most serious problems with water supply.<sup>13</sup> Their position at the end of the Eastern Canal was further from the feeder canal than that of any other corporation. Head losses over such a distance were serious, and the sharp turn in the Eastern Canal made things worse. In addition, every mill on the route from the Swamp Locks affected the water level at the Boott head races.

The lower level Pawtucket Canal normally received its water supply from the tail races of the machine shop and the Hamilton, Appleton, and Lowell mills. The Proprietors of Locks and Canals did not want water passing over the Swamp Locks dam and wasting thirteen feet of head. The engineering plan called for water to generate power on both levels, to enter the lower canal only after leaving a factory wheel pit. In order to make this plan work, the upper level water users had to discharge at least as much water as the lower level mills required.

The canals formed a dynamic system which was only in equilibrium when proper water levels were maintained. There was some allowable fluctuation about the two separate equilibrium points, thirty and seventeen feet of elevation: but the operators of the system had to monitor the levels and take swift action if any drastic instability appeared.<sup>14</sup> The mills on the lower level, such as the Boott, were quick to complain if the elevation of their water began to fall. They could run with decreasing power until the level slipped below their lowest gate opening. A drop of about three feet from the contracted level would stop breast wheels completely and halt almost all manufacturing in the affected mill complex.<sup>15</sup>

Reduced discharge from upper level mills into a lower level canal could be offset by allowing supplemental water to flow directly from the upper to lower level. On the Western Canal, this could be done at the Hickey Hall Dam; on the Pawtucket, the extra water could be released at the Swamp Locks Dam. The men operating the system liked to know in advance of any shutdown which would affect water levels. It took time to restore the balance in the system once a change was detected, and the cause of a drop in water level was not always obvious.

The head in the lower Pawtucket could fall without any reduction in upper level discharge or leakage at the Lower Locks. If one or more of the lower level mills suddenly increased its demand for water, without the knowledge of Locks and Canals officials, then the unexpected drawing of extra water would exceed the normal input into that level and cause a drop in elevation. Such a situation would hurt all the other mills on the same level.

Before mid-century, Locks and Canals experienced difficulty in controlling the exact amount of water drawn by each corporation. A drop in water level was one indication that some company might be taking more water than the agreed amount. The methods available to measure water usage were difficult, expensive, and time-consuming. Special apparatus had to be set up to test the flow in a single raceway, and constant monitoring was not practical.<sup>16</sup>

The agent of the Proprietors of Locks and Canals was the enforcing authority on the canal system. In the early years, Kirk Boott personally settled disputes over power allocation and could order a corporation to halt excess usage of water. Because the river usually supplied more water than required for the leased mill powers of all the textile companies, the agent allowed some mills to draw more than their allotted shares. Usually this created no problems, but there were some protests over Boott's apparent favoritism to the Merrimack Manufacturing Company.<sup>17</sup>

The Lawrence Manufacturing Company did not approve of Boott's position as agent of both the Merrimack Manufacturing Company and the Proprietors of Locks and Canals. As early as 1834, Boott was accused of favoring his own textile company in a dispute over the purchase of additional mill powers by the Lawrence mills. He asked a higher price for the powers than the Merrimack Company had ever paid, and the evidence suggests that his own mills consistently drew a heavy supply of surplus water without any additional payment.<sup>18</sup>

The Merrimack mills were in a unique position on the canal system. They stood at the end of the upper level Merrimack Canal and discharged directly into the river, instead of into a lower level canal. Thus, the operators of the system would not notice an excess discharge from these mills. When the Merrimack Company was drawing more than its share, the excess demand was satisfied by the upper Pawtucket at the Swamp Locks Basin, and it was difficult to tell which of the three upper level power canals was putting a strain on the system. If surplus water was available, it was simpler to increase the flow through the sluice gates at the guard locks than to prove who was using too much power. With Boott as agent, there was also the possibility that the Merrimack mills received special treatment.

The autocratic Kirk Boott died in 1837 after fifteen years as the most powerful man in Lowell.<sup>19</sup> The obvious conflict of interest created by his two executive positions ended with his death, but disputes over water power remained a persistent problem for Locks and Canals. Joseph Tilden served briefly as agent after Boott and was then replaced by Patrick Tracy Jackson, one of the founders of the city. Under Jackson, the water power company made frequent use of impartial committees and consulting engineers to decide questions of water usage and provide technical information for planning.

In the summer of 1839, the Proprietors of Locks and Canals asked James Baldwin "to measure the water used by the several companies at Lowell." The indentures of water power stipulated that such tests were to be conducted in the tailraces of the mills, but Baldwin could not get accurate measurements there.

Jackson explained that the "raceways are so narrow that the water runs in them with great rapidity and very deep." He ordered the attempt abandoned until some better method could be determined.<sup>20</sup>

Jackson was determined to distribute water power according to need and to charge for the actual quantity drawn in normal operations. He knew that some corporations used much more than the actual amount prescribed in their indenture with Locks and Canals

I have reason to suppose that the Agents of the several companies who have purchased water power of this Company, will agree with me that it is desirable to have the Indentures...revised, and modified so as to make them more satisfactory to all parties, and it may be thought best to do this while some of those who assisted in making out those Indentures are still alive<sup>21</sup>

The agents of some of the corporations on the system apparently agreed with Jackson and proposed a new attempt at measuring water usage. Acting on this request, the Proprietors of Locks and Canals appointed three engineers to a special commission on May 6, 1841. Baldwin, George Whistler and Charles Storrow were elected for their professional skills and objectivity.<sup>22</sup>

The engineers received permission to determine water usage by measuring the flow in the canals instead of in the much narrower tailraces. They first tested the Western Canal and found a flow of five hundred eighty four cubic feet per second. The Tremont Mills and the Suffolk Manufacturing Company used the entire flow of the canal, but each paid for only four and one third mill powers. At the ratio of sixty and one half cubic feet per second for each mill power with a thirteen foot fall, they should have been using a total of five hundred twenty two cubic feet per second. The excess amounted to approximately one mill power, which they probably shared.<sup>23</sup>

In 1842 the Commission reported on the flow in the Hamilton Canal and in the Merrimack Canal below the entrance to the Lowell Canal. The Hamilton and Appleton corporations leased six and one half and four mill powers respectively, yet they drew thirty seven and one half cubic feet per second more than their total of ten and one half mill powers warranted. The excess was over one half a mill power.<sup>24</sup>

The Merrimack Manufacturing Company was, as expected, the largest user of excess water. The gauged the flow in the Merrimack Canal at four hundred eleven cubic feet per second; one hundred sixty one more than the amount allowed for ten mill powers at twenty five cubic feet per mill power (thirty foot fall). The Merrimack Mills were taking almost six and one half mill powers without paying for them. This was accurately measured when the level of the canal was "nearly level with the top of their wheels."<sup>25</sup>

The only measurement listed for the lower level was of the water used by the Middlesex Company. The excess was over three mill powers, with much of it being drawn by a single new mill.<sup>26</sup> Other lower level measurements may have been made at a later date, but the determination of the upper level usage was the primary objective of the Commission. In normal operation, the lower level mills drew

only the amount of water discharged into their level by other mills. The excess usage on the upper level Western and Hamilton Canals provided the extra water available on the lower level of the system.

The commissioners did not measure the power used by the machine shop of Locks and Canals or by the Lowell Manufacturing Company, which was temporarily shut down. Excluding these water users from consideration, Jackson calculated that the mills on the upper level drew two hundred sixty and one half cubic feet per second in excess of the quantity leased to them. Since all this water had a total head of approximately thirty feet, dividing by twenty five gave over ten and one third as the number of surplus mill powers in normal use passing through the system.<sup>27</sup>

The directors of Locks and Canals appointed a committee to sell additional mill powers to the companies which wanted them. After the Merrimack Manufacturing Company refused to pay six dollars per spindle (3586 spindles per mill power) for the extra power it was already using, the directors agreed on a price of four dollars per spindle. The same rate was offered to other companies, but the Middlex Corporation had to pay an additional \$5000 for back rent of water power.<sup>28</sup>

The leases of 1843 were for additional water only and did not affect previous indentures. As a result of several measurements of available flow in the Merrimack River,<sup>29</sup> the Proprietors of Locks and Canals agreed to provide even more water than was already in use (legally or illegally) on their system. Several corporations leased more than they had been drawing and were able to expand their manufacturing operations because of this increased power.<sup>30</sup>

The following table shows the power leased up to 1843 and the additional leases made in that year:<sup>31</sup>

Corporation	Pre-1843 Leases	1843 Leases	Total Mill Power
Merrimack	10	6-1/2	16-1/2
Hamilton	6-1/2	2-1/2	9
Appleton	4	1-1/2	5-1/2
Lowell	4	1	5
Tremont	4-1/3	1	5-1/3
Suffolk	4-1/3	1	5-1/3
Lawrence	11-1/2	2-2/3	14-1/6
Middlesex	1	2	3
Boott	9	1	10
Massachusetts	9	1	10
Total	<u>63-2/3</u>	<u>20-1/6</u>	<u>83-5/6</u>

The total mill powers leased by any corporation still represented a minimum quantity which that company could count on for year round operations. During most of an average year the Merrimack River supplied the canal system with more than all the leases required. The leases were conservative because dry, hot summers radically reduced the flow in the river and made it difficult for Locks and Canals to meet its obligations.<sup>32</sup>

Production figures did not rise significantly after the new leases were put into effect because many of the corporations had been using almost all the water they could, despite the limitations in the old leases. In 1842, the corporations on the system produced 70,275,400 yards of cloth with 194,333 spindles and 6,048 looms. This was actually a poor year; the previous year's total was 73,853,400 yards. One year after the signing of the additional leases, annual production had only risen to 75,873,200 yards, with 204,076 spindles and 6304 looms in use.<sup>33</sup> The reallocation of water power had not solved the serious hydraulic problems in the system.

When water was high in the river, Locks and Canals had no difficulty providing leased quantities of flow, but the lower level mills then needed far more water than they had contracted for. "Backwater conditions" meant that water in the river had risen into the wheelpits of the lower level mills and was impeding the rotation of their wheels. Only a very heavy flow of water into the floats of the breast wheels would produce enough power for manufacturing operations during backwater.<sup>34</sup>

Backwater was the bane of mill owners all over America. Wherever tailraces were subject to seasonal flooding, water wheels could not be depended on for efficient year-round operation. Francis Cabot Lowell, the founder of the Lowell system at Waltham, had been deeply concerned about backwater at his first mill site. His eagerness to alleviate this problem led him to make one of his few bad investments. He became interested in a machine of dubious capability and wrote glowingly of his faith in it in a letter of December 31, 1814:

Jacob Perkins of Newburyport...has invented a machine for removing the back waters from the wheels of mills...Almost every mill in this country loses from one-quarter to one-third of their power in consequence of being obliged...to get rid of the backwater...We have tried this machine in erecting our new mill at Waltham...I am so well satisfied with this invention that I have bought off Mr. Perkins half of the patent...so that I have the exclusive right to sell it.<sup>35</sup>

Perkins' machine did not solve the problem of backwater, which continued to plague mill owners for many years. One set of nineteenth century statistics from Lowell shows that backwater existed an average of several working days per year over a period of twenty-two years.<sup>36</sup> Mills with tailraces emptying into the Merrimack and Concord Rivers were vulnerable to this high water problem, but another form of backwater sometimes troubled mills discharging into a lower level canal. In 1842 the Tremont and Suffolk mills were regularly inconvenienced by high water on the lower level of the Western Canal. Apparently the Lawrence Manufacturing Company was not drawing enough water to keep up with the discharge of the upper level companies. They were considering raising their breast wheels one foot to avoid "the constant complaint of back water" caused by the Lawrence mills.<sup>37</sup>

The imperfections in the canal system were troubling to the engineering specialists of Locks and Canals, who were determined to improve and expand the production of water power. James Francis had been in charge of hydraulic engineering since he came to Lowell after the death of Joel Lewis in 1834. When George Whistler, who had hired Francis as his assistant, left Locks and Canals in 1837, the young Englishman was appointed chief engineer of the company in his place. At the age of twenty-two, Francis was suddenly responsible for engineering in the machine shop, the construction of new mills, and the operation of the entire canal system.

The new chief engineer was an amazingly well organized and efficient man, capable of supervising numerous activities simultaneously and of educating himself in several disciplines while he worked. Francis had little formal academic training, having begun his professional career at the age of fourteen as the assistant to the engineer building the harbor works at Porth Cawl in South Wales. His work on that project, on the Grand Western Canal in England, the Stonington Railroad in Connecticut, and the canals at Lowell gave him a degree of practical experience which befitted his new position, even if his age and schooling did not.<sup>38</sup>

Despite the wide range of his engineering and scientific interests, Francis was primarily concerned with hydraulics and fascinated by the potential of the Merrimack River at Lowell. He studied both the practical achievements of hydraulic engineers and the underlying scientific principles which explained the behavior of water. Lowell was to become a great laboratory for James Francis, a place in which he could test the theories of European and American experts, perform original experiments, and put into practical application the results of his research. Improvements in the canal system under his direction would be the result of careful engineering calculation and scientific experimentation as well.

Other talented engineers helped Francis to evaluate the potential of the Merrimack River and the effectiveness of the existing canal system. Locks and Canals hired consultants for special projects and formed commissions to settle delicate questions such as the actual use of water power. Francis became well-acquainted with James Baldwin, a frequent paid consultant, and with Uriah Boyden, a former full-time employee still working on occasional projects for Locks and Canals as a professional engineer. He also knew Charles Storrow, a Harvard graduate who had written the first scientific text on hydraulics in the English language and had helped measure flow rates in the Lowell Canals.<sup>39</sup>

Although Francis spent a great deal of time doing surveys of the Merrimack River, studying hydraulics, and discussing engineering theory with his knowledgeable friends, he also had to supervise the maintenance and operation of the canals. While laying plans for grand changes in the overall system, he handled countless minor engineering problems with characteristic thoroughness. He filled journals and workbooks with precise calculations and notations on projects in which he was involved. Those of engineering interest he documented with great detail, often with accompanying sketches or formal drawings.<sup>40</sup>

Locks and Canals had become a large company, and its chief engineer had his hands full with the many tasks assigned to him. Francis had to ensure that the canal system not only supplied adequate water power for manufacturing but also functioned as a transportation route around Pawtucket Falls. By the original charter of 1792, the company was obligated to maintain the transportation capability of the Pawtucket Canal. This meant keeping the locks in good repair, a serious problem by the late 1830's.

The heavy timber gates and plank side walls, installed to make the lock chambers waterproof, had deteriorated badly since the building program of the early 1820's. Repair of the guard locks began in 1839, but the directors of Locks and Canals were lobbying in the state legislature for a change in the provisions of their original charter. The lock chambers described in that document had to take rafts of timber "not exceeding twenty-five feet in width." The directors wanted, and got, a narrower width requirement. On February 28, 1840, the legislature decreed that "The said Proprietors, on rebuilding the locks on their canal at Pawtucket Falls ... shall not be required to build them more than twelve feet wide in the clear..."<sup>41</sup>

Narrower locks would take less time to fill and waste a smaller amount of water which could be used for power generation. After initial construction, they would also be less costly to repair. Patrick Tracy Jackson ordered the rebuilding of the Swamp Locks soon after the new act had passed. He delayed reconstruction of the Lower Locks until the following year, and finished the repairing of the Guard Locks without narrowing.<sup>42</sup> There was only a single lock chamber at the Guard "Locks" and a minor difference in elevation between the river and the upper level of the Pawtucket Canal. Also the twenty-five foot width of the chamber made it easier to transport timber rafts to the sawmills and lumber yards just a few hundred yards down the canal.

At the Swamp Locks, the two lock chambers were narrowed to twelve feet with wooden construction within the original rubble stone walls. Jackson had also considered stone lining for the narrowed chambers, but the estimated cost of \$7,000 was far higher than the \$2,000 figure for wood. He argued that, "These linings of wood are to be so constructed that they can be repaired in any season, without stopping the boating on the Canal, and without any great expense for keeping out the water - and it will be found that they will be cheaper than the stone lining if they will last fifteen years - our present linings have been in since 1822."<sup>43</sup>

James Francis wrote that "the sills and the lining plank were of pine, and the side frames of oak." New stonework was required at each of the three sets of gates and at the dam beside the locks. All of the new construction and repairs at the Swamp Locks cost \$9,204.12, a significant increase over the \$6,843.52 spent at the Guard Locks.<sup>44</sup>

The most expensive part of the rebuilding program was the Lower Locks, which were the deepest on the system. As at the Swamp Locks, masons narrowed the walls around the wooden gates with "cut granite, laid in hydraulic cement" and remodeled the dam. The new dam began with a sloping, timber-covered section and ended below in a series of granite steps. The workers also built stone walls in

the bottom part of the lower lock, but finished the reduction of the chambers with the same type of wooden construction used at the upper locks. The cost came to \$26,214.91.<sup>45</sup>

Although Patrick Tracy Jackson expected "that the Tolls on the Pawtucket Canal will pay all the Annual expense for repairs for many years;"<sup>46</sup> the heyday of canal transportation was coming to an end. In a way, Jackson was responsible for the declining receipts of the toll collectors. He was the major promoter of the Boston and Lowell Railroad, which had opened in 1835 as a major competitor of both the Middlesex and Pawtucket Canals.

Jackson's railroad company was chartered in 1830 over the strident opposition of the directors of the nearby Middlesex Canal. The canal carried the British locomotive, Stevenson, to Lowell, where Whistler, Francis, and the mechanics of Locks and Canals produced their own version of the steam engine. When their locomotive, named the Patrick for Patrick Tracy Jackson instead of the possibly misunderstood Jackson, ran from Lowell to Boston along practically the same route as the canal, the days of the Middlesex were numbered.<sup>47</sup> The usefulness of the Pawtucket Canal also began to decline after that fateful trip in the summer of 1835.

The transportation capability of the Pawtucket Canal was very important before the railroad linked the mills directly to the markets of Boston. Canals carried construction materials and raw cotton into the city and brought out finished cloth. The Middlesex Canal was less than a mile up the Merrimack from the entrance to the Pawtucket Canal, and its twenty seven mile route to Boston Harbor was the normal path for cargo to and from Lowell. The agent of the Middlesex Canal reported in 1825 that "We have succeeded in bringing into our channels the carrying trade of the manufacturing companies in Chelmsford (Lowell) at certain reduced rates of toll..."<sup>48</sup>

The Middlesex had to drop its rates to win and hold the business of the Lowell companies, who sometimes used teamsters to drive down the price of canal transport. The competition of the teamsters could be overcome, but the opening of the Boston Lowell Railroad was a different matter. Within a few years after a rail spur reached the Lawrence mill yard, Locks and Canals closed off a special set of locks constructed in 1833 to link the Lower Western and Lawrence Canals with the upper level and the Pawtucket Canal. The Lawrence mills no longer needed a water route to the Pawtucket and Middlesex Canals.<sup>49</sup>

The spread of railroads into New Hampshire in the 1840's was the final blow for the Middlesex Canal, which had struggled on with a small flow of northern traffic. Rafts of timber alone could not support its operation, and the owners petitioned the legislature to dissolve in 1850.<sup>50</sup> The Pawtucket Canal was still functioning as a transportation system, though it would never have survived on the meager toll receipts after 1835.

The rates of toll for the Pawtucket Canal were listed on a wooden signboard. In the 1830's, most of the items were timber products, although bricks, iron, stone, coal, lime, salt, hay, and manure also had set rates. The cost of passage ranged from eight cents per ton of coal to one dollar per "board-measure" of white-oak pipe staves. The sign stated that "Articles that do not pass through more than three locks (are) to be charged only half the above rates of toll."<sup>51</sup>

In 1833, the toll collector on the Pawtucket Canal took in \$10,870.80. In 1834 the total was \$9,158.96; but the following year brought the railroad, which cut receipts almost in half. In 1838 the annual return was only \$2563.79. Receipts rose slightly during a period of major construction in the late 1840s, but dropped again to a low of \$1,751.30 in 1852.<sup>52</sup>

Locks and Canals had to keep the Pawtucket Canal operational for boats and rafts, even if the costs of maintaining the locks exceeded the annual toll receipts. The charter of the company was the basis for all its diversified activities, and that charter had been issued to the operators of the canal.<sup>53</sup> Many businesses depended on the Pawtucket Canal for the transport of lumber and masts.

Lumber companies in Lowell were situated on the upper Pawtucket Canal between the Guard Locks and the Swamp Locks. Rafts of timber came down the canal to their yards and were often stored afloat in small coves just off the main channel. Whenever their floating stockpiles drifted into the canal and disrupted the steady flow of water, the chief engineer was quick to complain. For many years, these coves were a nuisance to Locks and Canals.<sup>54</sup>

Some of the timber passed completely through the Pawtucket Canal and on to Newburyport, where masts and lumber for the ship-building industry were still in demand. The traffic on the Merrimack was greatest in the spring, for then rafts could float with comparative ease over most of the falls.<sup>55</sup> After leaving the Lower Locks of the Pawtucket, a raft of masts was soon bouncing swiftly over the rapids at Hunts Falls on its way to the seacoast.

Locks and Canals remained a transportation company even as the relative importance of canal traffic declined year by year. The other aspects of the company's operations dwarfed its services to raftsmen, but there was a certain romance to the river traffic which set it apart from manufacturing or the production of water power. As long as rafts entered the locks at Lowell, the canal company was still in touch with its eighteenth-century origins.

Manufacturing had been a major part of the operations of the Proprietors of Locks and Canals since the machine shop was taken over in 1825. By the mid 1830s, two main branches of manufacturing had evolved within the shop: one devoted to textile machinery and the other to locomotives. In addition, the shop made gate hoisting mechanisms and other machinery used on the canal system or on mill raceways.<sup>56</sup>

The machine shop was capable of precision machining on a large scale, but until 1840, castings were ordered from out of town. This costly arrangement prompted Locks and Canals to build a foundry near the complex of shop buildings. A piece of land was available between the Swamp Locks and the entrance to the Hamilton Canal. There the new foundry drew its water from the upper level in the Swamp Locks Basin and discharged into the lower level of the Pawtucket Canal just below the locks. A bridge connected the machine shop with its foundry.<sup>57</sup>

While the Proprietors of Locks and Canals were expanding their manufacturing facilities, the agent and the chief engineer were planning to increase greatly the power available for all types of manufacturing on the canal system.. Surveys begun in the late 1830s had pointed out the value of building a new canal to

bring additional water into the canal system. Although not everyone shared Patrick Tracy Jackson's enthusiasm for this long range project, he had good evidence to support his arguments.

In 1839, James Baldwin laid out a rough plan of a "proposed canal from Pawtucket Dam to the Western Canal." William Worthern, working under the direction of James Francis surveyed and drew the canal on a large sheet which could be studied by the directors of Locks and Canals. The channel, as planned, would begin at the falls and stretch almost half a mile beside the river before turning inland to link up with the Western Canal. The drawing also shows a modified dam, designed to channel the main flow of the river into the entrance of the proposed canal.<sup>58</sup>

Jackson ordered additional surveys to determine the amount of water flowing in the river, the storage capacity behind the dam, and the additional mill powers which the dam and canal could make available. The summer of 1840 being unusually hot and dry, he asked Francis "to ascertain the quantity of water furnished by the river in a given time" under the poorest conditions. Francis' report showed Jackson that "by holding up the water during the night 9 out of the 24 hours, we shall save enough to supply for the 14 hours the mills are running 28-2/3 mill powers more than we have sold."<sup>59</sup>

Jackson claimed that the additional mill powers "if worth the prices we have hitherto sold for, will more than meet the estimated expence of building the new canal." His plan depended on the acceptance of a fourteen hour restriction on power generation, for only if he ponded water behind his proposed dam all night could he supply the mill powers that would pay for the project.<sup>60</sup> Further research supported his claims for the potential of the river, but one of the companies on the canal system was reluctant to accept the time limit on power.

In 1841, Jackson reported to the directors of Locks and Canals "that the Merrimack Company, will not make such an arrangement as to the use of the Mill Power sold to them, as will enable this Company to hold up the water on the night time in such a manner as would justify us in building a New Canal." The plans were temporarily shelved, and the sale of mill powers in 1843 was limited to those which could be delivered without nightly ponding in dry weather.<sup>61</sup>

One of the engineers who had helped Jackson to measure the capacity of the river was soon at work on an important engineering project of his own. Uriah Boyden had heard of a new French device called a turbine, reportedly a more effective means of converting the energy of water to mechanical power than any of the breast wheels then in use in Lowell. Recognizing the value of the turbine, he began to study the principles of its operation and to test its applicability for American manufacturing. Boyden, like Francis, was both an inquisitive, scientific theorist and a practical engineer.

Born at Foxborough, Massachusetts in 1804, Boyden spent most of his youth laboring with his father at farming and blacksmithing. He helped his brother manufacture malleable iron and patent leather in Newark, New Jersey and ran a leather splitting shop in Cambridgeport, Massachusetts. His first training in engineering came as the assistant to James Haywood on the survey for the Boston and Providence Railroad. He also learned from Laommi Baldwin, Jr. during the construction of the great dry dock at the Charleston Navy Yard. When he came to Lowell in the early 1830s, Boyden went to work as one of the bright, young engineers of Locks and Canals.

His first projects at Lowell were the construction of the Suffolk, Tremont, and Lawrence mills. He worked for Jackson on the Boston and Lowell Railroad and directed the building of the Nashua and Lowell. Moving to Manchester for two years, he was the hydraulic engineer for the newly formed Amoskeag Company. He continued to consult for Locks and Canals and, from 1836 on, kept an office in Lowell.<sup>63</sup>

Boyden's growing interest in the underlying principles of hydraulics led him to study the work of French scientists. He had exceptional mathematical ability and could understand the theoretical aspects of water power engineering. When he learned of Benoit Fourneyron's claims for the invention of a practical turbine, Boyden carefully analyzed the ideas of the Frenchman and determined that he could build a better turbine of the same basic type.<sup>64</sup>

Fourneyron had installed his first turbine at Pont-sur-l'Ognon in 1827, but American engineers were not aware of the turbine's potential for over a decade. The first brief mentions of the turbine in the Journal of the Franklin Institute in the late 1830's attracted little attention. An article by Ellwood Morris in two 1842 issues contained the first detailed American description of the Fourneyron turbine. Morris, a Philadelphia engineer, built several turbines and carried out a series of experiments which he also reported in the Journal.<sup>65</sup>

The Fourneyron turbine is classed as a "reaction wheel" because much of its power is derived from the reaction caused by water pressure on the blades of its runner. The velocity of the water as it enters the runner is not as high as the elevation of the water source could produce. Much of the energy due to head, or elevation, is converted to pressure energy instead of kinetic energy. The kinetic energy due to water velocity imparts some power to the runner through impulse, but most of the turbine's power comes from reaction due to pressure energy.<sup>66</sup>

In the Fourneyron turbine, water enters near the center of the wheel, around the shaft on which the runner is mounted. The water moves in an outward direction through curved guide passages and exits by passing between the vanes of the runner. The runner vanes, also curved, are on the periphery of the turbine, surrounding the fixed guides. As the water moves through the "buckets" formed by the vanes, it gives energy to the runner and sets it in motion. The runner drives the shaft, from which power can be transmitted mechanically by gearing or belting.<sup>67</sup>

Fourneyron, like all successful inventors, profited from the work of other men in the design of his turbine. Invention does not take place in a vacuum but instead is always based to some extent on prior experience and outside influence. Hydraulic science had been an active field of inquiry on the Continent since the eighteenth century. The work of men like Leonard Euler, Jean Victor Poncelet, and Claude Burdin was as essential in the development of the turbine as Fourneyron's successful "invention."<sup>68</sup> As Boyden set out to build an improved turbine, he became one of a large group of scientists, engineers, and tinkers who were all working on the same basic hydraulic problems, through often in different ways.

Boyden installed a turbine in the picker house of the Appleton Company in 1844. His was a better design than Fourneyron's, but the basic reaction principle and outward-flow characteristics were the same. The measured efficiency was seventy eight percent and James Francis later attested that, in this wheel, "Mr. Boyden introduced several improvements of great value." Two years later, Boyden built three additional turbines for the Appleton Company which were superior to his first wheel. He patented his modifications of the Fourneyron design, including the Boyden diffuser, which added several per cent to the efficiency of an outward flow turbine.<sup>69</sup>

The Proprietors of Locks and Canals were not initially involved in Boyden's development of the turbine. Although the canal company had purchased patent rights to a different type of turbine in 1838, none had been installed in a Lowell mill. Boyden's turbine in the Appleton picker house was the first to operate with water from the canal system. James Francis' supervision of the formal testing of Boyden's next group of turbines in 1846 shows that the engineering management of Locks and Canals had become deeply interested in the potential of this new form of water wheel.<sup>70</sup> By that time, however, the company had lost its manufacturing branch.

The machine shop of Locks and Canals had brought great profits to that company since 1825. Despite a few slow years, the combined production of locomotives and textile machinery was the most lucrative area of the company's overall operations. Business records in 1838 allow a comparison of profits from four areas of operation:<sup>71</sup>

Mill rents (water power)	\$ 7,579.53	11%
Other rents	5,126.04	8%
Machinery	40,000.23	58%
Locomotives	15,722.24	23%
Total Operating Profit	68,437.04	100%

Usually, when locomotive orders were down, textile machinery was in demand, and vice versa. In the meantime, the value of land and water power was rising. Profits from water rents rose dramatically after the sale of additional mill powers in 1843. With the possibility of a new ponding agreement, further canal construction might greatly increase the number of available mill powers. The Proprietors of Locks and Canals held extensive capital assets in the form of land, water, and the machine shop, yet by the early 1840's many of the stockholders were becoming nervous about the company's prospects for continued profitability.<sup>72</sup>

Stock in Locks and Canals had been purchased for \$500 in 1825. In 1836, the value had risen to \$1820 per share, but by 1843, a share brought only \$700. This decline in value was certainly not reflective of the company's record for substantial dividends. In the years from 1825 to 1844, each share had paid \$1422.50 in dividends, an average return of fifteen per cent per year. Jackson was angered by what he considered to be an unjustified loss of stockholder confidence in a profitable company. Still, he could not deny that machinery and locomotive orders were becoming uncertain.<sup>73</sup>

As early as 1841, the directors of Locks and Canals were considering the possible sale of the machine shop. Sale was finally authorized for \$200,000 in September, 1844, and after a period of bargaining with Abbott Lawrence, the directors settled on a price of \$175,000. The shop became the Lowell Machine Shop, a separate corporation and a purchaser of water power from the reorganized Proprietors of Locks and Canals.<sup>74</sup>

In addition to selling the machine shop, the directors also sold \$600,000 worth of property to the textile corporations. All the stock in Locks and Canals was called in and the total assets of the company determined. Each stockholder received \$1,582 per share. This sum plus the dividends paid to date added up to an average return of twenty four per cent per year since 1825. The company, reorganized under the same name, became wholly owned by the purchasers of its water power.<sup>75</sup>

This complete change of ownership in 1845 placed all the company's stock in the control of the various corporations on the canal system. The subscription of stock by each corporation was proportional to its share of the total allotted mill powers.<sup>76</sup> Thus the Merrimack Manufacturing Company, which used the most water, became the largest stockholder in Locks and Canals. No longer would some private stockholders view the canal company as purely a profit-making organization; more than ever, it had become a servant of the textile corporations, and its policies would reflect the attitudes and interest of the water users.

The reasons for the sale of the machine shop and reorganization of Locks and Canals are unclear. Perhaps, as in 1825, multiple operations under one company had become unwieldy. The reorganization did leave Locks and Canals in charge of the canal system and nothing else. Some may have viewed the machine shop as a potential liability and sought an immediate return from its sale. Whatever the actual reasons for the events of 1845, the textile corporations ended up with complete control of their supplier of water power.

The year 1845 also marked the end of Patrick Tracy Jackson's tenure as agent and treasurer of Locks and Canals. Claiming that the reduction in property and company activities made his further services unnecessary, Jackson resigned.<sup>77</sup> In selecting a new agent, the directors were apparently influenced by the possibility of losing their chief engineer to the newly formed Essex Company, which was planning a major industrial development on the Merrimack, downstream from Lowell. James Francis received a raise and a new position as both agent and chief engineer of Locks and Canals.<sup>78</sup>

The Essex Company, with Charles Storow as its chief engineer, began to build a massive dam and a planned industrial city just nine miles from Lowell. This venture was not directly competitive with Locks and Canals or the other Lowell corporations; in many ways, the new community of Lawrence was almost an expansion of the older textile city. Its founders included men with strong financial ties to Lowell: investors such as Smauel and Abbott Lawrence, Patrick Tracy Jackson, and Nathan Appleton.<sup>79</sup>

The success of Lawrence, like that of Lowell, depended on water power from the Merrimack River. In 1845, Samuel Lawrence conceived an ingenious plan to improve the flow of the river in dry seasons by gaining control of the northern lakes which fed it.

After the work on the dam at Lawrence had been commenced, I became alarmed lest the control of those grand reservoirs should be in the hands of parties not in harmony with the mill-owners on the main stream, and formed the project of buying their outlets, consisting of water-falls, mills of various kinds for many purposes, lands and houses, owned by individuals, firms, and corporations, over a large extent of territory.<sup>80</sup>

Once this plan was implemented, the storage in the lakes was increased in the spring, and water was drawn off as needed in the summer.<sup>81</sup>

The very idea of purchasing lakes for use in controlling a great river struck some observers as a classic example of human arrogance. Ralph Waldo Emerson wrote the following satirical account of this project in his journal.

An American in this ardent climate gets up early some morning and buys a river; and advertises for twelve or fifteen hundred Irishmen; digs a new channel for it, brings it to his mills, and has a head of twenty-four feet of water.....sends up an engineer into New Hampshire, to see where his water comes from, and after advising with him, sends a trusty man of business to buy of all the farmers such mill-privileges as will serve him among their waste hill and pasture lots, and comes home with great glee announcing that he is now owner of the great Lake Winipiseogee, as reservoir for his Lowell mills at midsummer. They are an ardent race, and are fully possessed with that hatred of labor, which is the principle of progress in the human race, as any other people. They must and will have the enjoyment without the sweat. So they buy slaves, where the women will permit it; where they will not, they make the wind, the tide, the waterfall, the stream, the cloud, the lightning, do the work, by every art and device their cunningest brain can achieve.<sup>82</sup>

James Francis was not satisfied with the control of the northern lakes; he wanted full control of the pondage above the Pawtucket Dam as well. Jackson's plan for storing water during non-working hours was revived in the mid-1840's and with it the entire program for expanding the water power at Lowell. A modified dam and a new canal would make possible more efficient use of the improved flow of the Merrimack. Francis may also have foreseen that Boyden's development of the turbine would soon revolutionize the generation of power in Lowell and make the proposed canal even more valuable than Jackson had dreamed.

Lowell was ready for a new canal. With the northern lakes under Francis' control, he was assured of a substantial year-round flow; but the aging Pawtucket Canal was already overstrained and becoming increasingly inefficient. He could not supply the power for further industrial expansion on the canal system unless he was authorized to construct another main feeder from the upper river. In 1846, he was to get his chance to direct an engineering project of enormous scale and great technological sophistication; the Northern Canal would be one of the most impressive engineering achievements of his century.

FOOTNOTES CHAPTER IV

<sup>1</sup>See Statistics of Lowell Manufactures. January 1, 1837 and January 1, 1842. Annual statistics published in Lowell were collected in a scrapbook by Locks and Canals, 1835-1187. The 1842 Statistics contain an historical sketch with census data.

<sup>2</sup>Ibid., January 1, 1837.

<sup>3</sup>See Ibid., January 1, 1838; and George Gibb, The Saco-Lowell Shops; Textile Machinery Building in New England 1813-1949 (Cambridge, 1950), pp. 98-99.

<sup>4</sup>See Gibb, The Saco-Lowell Shops, p. 76; Locks and Canals, "Book of Indentures"; and Locks and Canals, Francis' Records A, November 16, 1840.

<sup>5</sup>Statistics of Lowell Manufactures, 1846-1848.

<sup>6</sup>Analysis of various maps in Locks and Canals vault. See also John Coolidge, Mill and Mansion (New York, 1967), pp. 22-27.

<sup>7</sup>Margaret Parker, Lowell: A Study of Industrial Development (New York, 1940), pp.

<sup>8</sup>Harriet Robinson, Loom and Spindle (New York, 1898), pp.

<sup>9</sup>Contemporary evaluations of the canal system before 1848 have not been found, but it is possible to make conclusions on early hydraulic efficiency by relying on later reports, early canal plans, and the basic theories of fluid dynamics. The early hydraulic problems often remained to bother James Francis and his successors. The system today can still reveal a great deal about past difficulties.

<sup>10</sup>See Julian C. Hinds, "Canals, Flumes, Covered Conduits, Tunnels, and Pipe Lines," in Calvin C. Davis, ed., Handbook of Applied Hydraulics (New York, 1942), pp. 457-463; and Daniel Mead, Water Power Engineering (New York, 1908), pp. 72-76.

<sup>11</sup>See Locks and Canals, Directors' Records, Report by J.B. Francis, February 5, 1848; Locks and Canals, "Sundry Papers," Report to Directors by J. B. Francis, September 17, 1855; and William Worthen, "Life and Works of James B. Francis," CORFA, V, p. 235.

<sup>12</sup>Locks and Canals, "Sundry Papers," Report to Directors by J.B. Francis, September 17, 1855.

<sup>13</sup>Ibid. Even in 1855, after major improvements in the system, the total head loss from the entrance of the Pawtucket to the Boott Cotton Mills was measured at 3.31 feet.

<sup>14</sup>Locks and Canals, "Sundry Papers," Report of Commission, November 28, 1853. This report shows the difficulty of maintaining heights in the system. Modern practice is also instructive on this subject.

- <sup>15</sup>Locks and Canals, Francis' "Records," A Summary of experiments on the breast wheel in the Machine Shop, 1844. The top of the lowest of the three gates was 37 inches below the top of the wheel.
- <sup>16</sup>Locks and Canals, Directors' Records, Report by P.T. Jackson, September 10, 1840, and September 20, 1842.
- <sup>17</sup>See Gibb, Saco-Lowell Shops, p. 87; and
- <sup>18</sup>Same as above.
- <sup>19</sup>The most forceful argument for Boott's importance is in Coolidge, Mill and Mansion.
- <sup>20</sup>Locks and Canals, Directors' Records, February 19, 1839, and Report by P.T. Jackson, September 10, 1840.
- <sup>21</sup>Ibid., Jackson's Report, September 10, 1840.
- <sup>22</sup>Ibid., September 21, 1841.
- <sup>23</sup>Ibid., September 20, 1842.
- <sup>24</sup>Ibid.
- <sup>25</sup>Ibid.
- <sup>26</sup>Ibid.
- <sup>27</sup>Ibid.
- <sup>28</sup>Ibid., October 14, 1842, January 28, 1843, May 29, 1843, and September 9, 1842.
- <sup>29</sup>Ibid., September 12, 1840, and September 20, 1842.
- <sup>30</sup>Locks and Canals, "Book of Indentures."
- <sup>31</sup>Ibid.
- <sup>32</sup>See Locks and Canals, Directors' Records, September 12, 1840; and Locks and Canals, "Merrimack River Survey," August 1, 1927.
- <sup>33</sup>Statistics of Lowell Manufactures, 1842-1845.
- <sup>34</sup>Locks and Canals, Directors' Records, Report by J.B. Francis, February 5, 1848, and authorization April 14, 1848.
- <sup>35</sup>F. C. Lowell to Peter Remson, December 31, 1814, Lowell Papers, Massachusetts Historical Society.

36Locks and Canals (B. L.), "Table showing the number of days of Backwater for each year from 1875 to 1897."

37Locks and Canals (B. L.), Hervey Hall to Directors of Locks and Canals, March 22, 1842.

38For biographical information on James B. Francis see Worthen, "Life and Works of James B. Francis," pp. 227-242; and Hiram F. Mills, "James Bicheno Francis," read to the Corporation of the Institute of Technology. December 14, 1892, pp. 1-8.

39Charles Storrow, A Treatise on Water-Works for Conveying and Distributing Supplies of Water; With Tables and Examples (Boston, 1835). Most of his book was based on the work of French theorists.

40Francis' papers, journals, workbooks, reports, and drawings are in the library of Lowell University, Harvard Business School, and Locks and Canals. Some are also in private hands.

41Charters, Additional Acts, and Other Documents Relating to the Proprietors of the Locks and Canals on Merrimack River, the Winnepissiogee Lake Cotton and Woolen Manufacturing Company, and the Manufacturing Companies at Lowell, Who Use the Water Power of Merrimack River (Cambridge, 1857), 1792 Charter and Act of February 22, 1840.

42See Locks and Canals (B. L.), ledger of expenses, 1839-1841, filed under FC 2; and Locks and Canals, Directors' Records, May 2, 1840, January 21, 1841, and September 21, 1841.

43See James B. Francis, Lowell Hydraulics Experiments

44See James B. Francis, Lowell Hydraulics Experiments (Boston, 1855), p. 104, Locks and Canals, Francis' Records A, p. 269; Locks and Canals (B. L.) expenditures filed under GC-4; and Locks and Canals, Directors' Records, September 11, 1841.

45See Francis, Lowell Hydraulic Experiments, p. 104; and Locks and Canals (B. L.) expenditures on Concord River Locks, 1841-1844, filed under FC 2.

46Locks and Canals Directors' Records, September 20, 1842.

47Christopher Roberts, The Middlesex Canal, 1793-1860 (Cambridge, 1938) pp. 154-158, 171, 174.

48Agent's report for 1824, quoted in Ibid., p. 149.

49See Roberts, The Middlesex Canal, pp. 149-153; Locks and Canals, Book of Plans A; and

50Roberts, The Middlesex Canal, pp. 159-160, 186-187.

51Sign, in possession of the Lowell Historical Society.

<sup>52</sup>Locks and Canals (B. L.) tolls filed under FC 1-3.

<sup>53</sup>Locks and Canals, Charter of 1792.

<sup>54</sup>Francis' Records

<sup>55</sup>See General George Stark, "Navigation of the Merrimack River," CORHA, III pp. 298-299; and Francis, Lowell Hydraulic Experiments, p. 103.

<sup>56</sup>Gibb, Saco-Lowell Shops, ppl 90-94.

<sup>57</sup>Locks and Canals, "Plan of Proposed Canal from Pawtucket Dam to the Western Canal," October 1839.

<sup>58</sup>Locks and Canals, Directors' Records, September 12, 1840.

<sup>60</sup>Ibid.

<sup>61</sup>Ibid., January 7, 1843, and January 14, 1843.

<sup>62</sup>See Obituary of Uriah Boyden by J. B. Francis in Boston Daily Advertiser, October 18, 1879; and Arthur T. Safford, and Edward Pierce Hamilton, "The American Mixed-Flow Turbine and its Setting," Transactions of the American Society of Civil Engineers, vol. LXXXV, 1922, p. 1251.

<sup>63</sup>Obituary by Francis.

<sup>64</sup>Locks and Canals, File #1076.3, "Paper on Turbines-Uriah A. Boyden," typed copy of a letter to the judges of the U.S. circuit court for Massachusetts, July 26, 1876. Boyden argues in a patent case involving Swain and discusses the history of his own turbine work indirectly. See pp. 5-16.

<sup>65</sup>See Ellwood Morris, "Remarks on Reaction Water Wheels Used in the United States; and on the Turbine of M. Fourneyron; and Hydraulic Motor, recently used with the greatest success on the continent of Europe." Journal of the Franklin Institute, vol. IV, 3rd series, No. 4 & 5, 1842, pp. 217-227, 289-305.

<sup>66</sup>Civil Engineering: Materials, Hydraulics, Waterwheels, vol. 399 of the International Library of Technology (Scranton, 1925), "turbine" section, pp. 3-4.

<sup>67</sup>See Ibid. pp. 2-3; and Safford and Pierce, "The American Mixed Flow Turbine," p. 1249.

<sup>68</sup>Boydon, "Paper on Turbines," pp. 5-15.

<sup>69</sup>See Francis, Lowell Hydraulic Experiments, pp. 1-6; and Safford and Pierce, "The American Mixed-Flow Turbine," pp. 1250-1252, 1302.

<sup>70</sup>See Francis, Lowell Hydraulic Experiments, pp. 2-3; Safford and Pierce, "The American Mixed-Flow Turbine," pp. 1241-43; and Locks and Canals, "Waste Book," 1837-1860, test of Boyden turbine in 1845.

<sup>71</sup>Gibb, Saco-Lowell Shops, p. 98.

<sup>72</sup>Ibid., pp. 98-100.

<sup>73</sup>See Ibid., pp. 99-101; and

<sup>74</sup>Locks and Canals, Directors' Records, September 21, 1841, September 25, 1844, March 10, 1845, and April 5, 1845.

<sup>75</sup>See Ibid., November 19, 1845, and November 29, 1845; and Gibb, Saco-Lowell Shops, pp. 102-103.

<sup>76</sup>Gib, Saco-Loweel Shops, p. 102.

<sup>77</sup>Locks and Canals, Directors' Records, August 30, 1845.

<sup>78</sup>Mills, "James Bicheno Francis," pp. 1-2.

<sup>79</sup>Helena Wright, New City on the Merrimack (Merrimack Valley Textile Museum, North Andover, Massachusetts, 1973), introduction.

<sup>80</sup>Samuel Lawrence to Charles Hovey, February 8, 1875, CORHA, I, p. 289.

<sup>81</sup>See Ibid.; Nathan Crosby to Samuel Lawrence, January 18, 1845, CORHA, I, p. 290; and Arthur T. Safford, "Merrimack River Storage Improvements," Textile World, February 14, 1925.

<sup>82</sup>Emerson, quoted in Ware, New England Cotton Manufacture, p. 145.

ENGINEERING AND INDUSTRY IN LOWELL: 1821 - 1880

by Patrick M. Malone<sup>1</sup>

ABSTRACT: Lowell was America's first great industrial city. Its remarkable economic growth from 1821 to 1880 was the result of sound engineering practices and intelligent business decisions. Engineers harnessed the Merrimack River to provide power for ten large textile manufacturing companies and a major machine shop. They also built railroads and locomotives which connected the city with distant markets and suppliers. Scientific experimentation was closely linked with technology in Lowell and produced important advances in textile chemistry, hydraulic theory, and turbine design. James B. Francis, Lowell's most famous engineer, made significant improvements in the design and operation of the city's complex canal system in order to satisfy demands for more industrial power. Despite his work, however, steam became increasingly important as a prime mover in Lowell's mills and shops; by 1880, steam power had surpassed water power. Lowell's great achievements in mechanical and civil engineering were largely responsible for its pacesetting position in a young industrial nation.

TEXT

Lowell became America's first great industrial city because of the power of the Merrimack River and the talents of an amazing group of engineers, businessmen, and workers. At the Pawtucket Falls, a natural drop of thirty feet through jagged rocks and rapids produced an excellent site for industrial development based on water power. Although a transportation canal around the falls had been completed in 1796, the manufacturing potential of the site was not fully appreciated until a quarter of a century later.

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In 1813, a Boston merchant named Francis Cabot Lowell began an industrial experiment which eventually led to the founding of a city at the Pawtucket Falls. During a visit to Britain, he had seen power looms in operation and had developed his own ideas about the factory system. On his return, he found financial supporters and formed the Boston Manufacturing Company to manufacture cotton textiles. With the aid of Paul Moody, a skilled machinist and an early mechanical engineer, Lowell rapidly put his ideas into practice. The two men developed a successful form of the power loom and built a factory in Waltham, Massachusetts. Then, for the first time anywhere, Lowell combined all the processes of cotton cloth manufacture in a single mill. Raw cotton entered his water-powered factory, and cloth emerged.

(1)

At the time of his death in 1817, Lowell's Waltham operations were famous, not only for their technological sophistication and steady profits, but also for an unusual type of corporate paternalism. Most of the labor force was made up of female operatives who lived in closely-supervised boarding houses near the mills. Many were New England farm girls, lured by good salaries and the promise of a comfortable and secure lifestyle. Lowell never intended for his female workers to become a permanent proletariat; he expected that, after a few years of factory labor in a proper social environment, they would return to their homes improved by the experience. His "Waltham system" attracted an ample supply of workers in an area where labor was often scarce and gave him a reputation as both a social reformer and an effective businessman.

Patrick Tracy Jackson, who managed the Waltham mills, and Nathan Appleton, a major shareholder and prominent merchant, wanted to expand textile operations, but the Charles River, at Waltham, provided insufficient water power for their plans. In 1821, they decided to find a new location where they could make and print calicoes, a form of cloth not yet machine-produced in the United States. This plan would require land, new factories, a print works, corporate housing, and a great amount of water power. Jackson and Appleton knew that the plain cloth made in Waltham had a reliable market, yet they dreamed of much greater and more varied production in an entire community created for textile

manufacture.

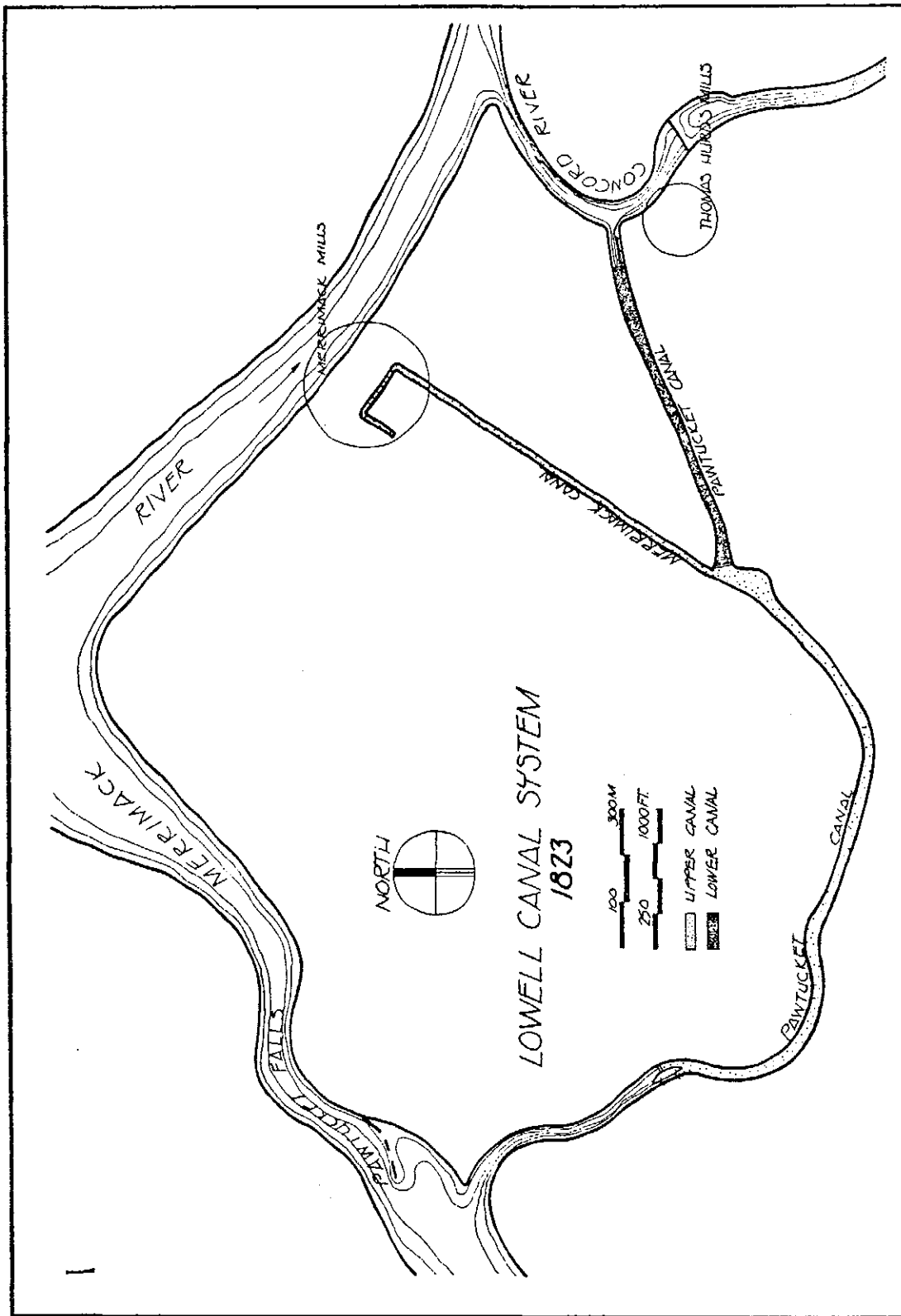
Appleton describes the selection of the area around Pawtucket Falls for the site of the new industrial community:

Our first visit to the spot was in the month of November, 1821, and a slight snow covered the ground. The party consisted of Partick T. Jackson, Kirk Boott, Warren Dutton, Paul Moody, John W. Boott and myself. We perambulated the grounds, and scanned the capabilities of the place, and the remark was made that some of us might live to see the place contain twenty thousand inhabitants. At that time there were, I think, less than a dozen houses on what now constitutes the city of Lowell, or rather the thickly settled parts of it... .(2)

There were a few small mills of various types in the area, but the decaying Pawtucket Canal was by far the largest engineering structure. The nine-thousand foot waterway had been built by the Proprietors of Locks and Canals on Merrimack River, a company chartered in 1792 to provide a route around the falls for rafts carrying timber and other northern products to the sea at Newburyport. By 1821, the canal was in bad shape, both structurally and financially. Its wooden locks were rotting, and most of its business had been captured by the competing Middlesex Canal, finished in 1803. The well-constructed Middlesex left the Merrimack River a mile upstream of the falls and took a direct, twenty-seven mile route to Boston Harbor.

Appleton, Jackson, and their associates easily acquired control of the Proprietors of Locks and Canals through large purchases of stock. At the same time, they bought up land and water rights in the immediate area of the falls and the canal. In 1822, they founded the Merrimack Manufacturing Company and began to plan for power canals, textile mills, and boarding houses. Kirk Boott, a former British Army officer with some engineering training, became the first agent of the new company and thus the resident supervisor of its construction program. Moody and Jackson, directors of the company and experienced technical specialists from Waltham, joined him to plan the best utilization of water power and the placement of the first mills. All realized that they would have to enlarge the old Pawtucket Canal and make it the main artery of a new canal system.

The ideal way to supply a number of mills with water power is to use a single canal running parallel to a river with a falls. If the canal leaves the river above the falls and re-enters at some distance



downstream, then the land between the canal and the river becomes an extended island on which mills can be placed in a line. (3) By keeping the level of water in the canal close to that of the river above the falls, there will be a major difference in water level between the canal and the river at every point below the falls. Water from the canal can enter the mills on the island to drop through power-producing machinery, such as water wheels, and then exit into the lower river. In this way, the potential energy of the water due to its elevation, or "head", can power manufacturing processes in each mill.

Unfortunately for the planners of Lowell, the topography of their site and the route of the existing canal were not suitable for implementation of the ideal scheme. The land on the south side of Pawtucket Falls was rocky and rose steeply from the river's edge. The builders of the Pawtucket Canal had avoided high ground by running their channel in a wide arc around the bend in the Merrimack and ending it at the Concord River, close to the junction with the larger stream. Since Boott could not place mills on land higher than the level of the upper river, he had to plan mill sites away from the falls and new canals to reach them. The Pawtucket would have to be reconstructed to feed smaller power canals, but the resulting system would obviously be a complex one, creating far more engineering problems than a single canal. An additional difficulty was the necessity of retaining the original function of the old transportation waterway. Construction supplies, raw materials, and manufactured products would be carried in the Pawtucket Canal for years.

In 1822, hundreds of laborers began work on the enlargement of the Pawtucket Canal and the construction of the new Merrimack Canal. This power canal running over three thousand feet to the first mill of the Merrimack Manufacturing Company was completed the following year. By removing the old Minx Locks of the Pawtucket Canal, Boott kept the water at approximately the level of the upper river all the way to the Swamp Locks Basin. From there, the Merrimack Canal led directly to the mill site, on the bank of the Merrimack but downstream of the bend. Water entering the mill was thirty feet above the level of the river at that point.

Nathan Appleton said that Paul Moody had "a fancy for large wheels"

and that "it was decided to place the mills of the Merrimack Company where they would use the whole fall of thirty feet." (4) On September 4, 1823, two days after letting water into the new power canal, Kirk Boott made the following notation in his diary:

Thursday, September 4, 1823. After breakfast, went to factory and found the great wheel moving round his course, majestically and with comparative silence. Moody declared that it was the "best wheel in the world." N. Appleton became quite enthusiastic. (5)

This "high breast" wheel was actually two wheels linked together, each thirty feet in diameter with buckets twelve feet long (when wheels of smaller diameter were later built in Lowell, the total length of buckets in a single mill was as much as sixty feet). Water entered the buckets near the top of the wood and iron wheel through a set of adjustable gates. Even if the level of water in the canal were to drop three feet, water could still flow onto the wheel from the lowest gate. This was the greatest advantage of the high breast wheel over the "overshot" wheel, for which the water level had to be higher than the top of the wheel. Both of these wheel types generated power because of the force of gravity acting on the water in their buckets. They turned in opposite directions, however; the breast wheel "pitched back," or rotated toward the sluice which delivered its water. This direction of rotation speeded the flow of discharged water out of the tail race. (6)

A good high breast wheel converted better than sixty per cent of the theoretical energy of the water into useful power for manufacturing. A combination of iron gearing and shafting in the Merrimack Mill transmitted power from the revolving wheel to each room in the building. The power output of the wheel was controlled by a flyball governor, an early form of feedback system which responded to changing power demands in the mill. The governor regulated the speed of the wheel by varying its gate settings. Paul Moody had built his first centrifugal governor at Waltham after listening to Francis Lowell's description of the flyball operation on a similar device in England. (7)

The new brick mill was 156 feet long by forty-five feet wide, with a basement, three stories, and a finished attic. Patrick Tracy Jackson designed the building to house approximately the same amount of

textile machinery as the second mill at Waltham, which had 3584 spindles on throstle frames and all the other machinery necessary to turn cotton into cloth. The water wheel and the heating furnace were in the basement. Machines, grouped by process, occupied all the upper floors, including the attic, where light was provided by clere-story windows. Although mills built in later years contained more spindles and were usually taller, the floor dimensions of Lowell mills did not change significantly until the 1840s. (8)

The textile machines for the first Merrimack Mill were built in the machine shop of the Boston Manufacturing Company at Waltham. Before the mill was completed, however, the directors of the Merrimack Manufacturing Company had acquired the patent rights for Waltham machinery and had arranged to move machinists, patterns, and machine tools from Waltham to the new community at Pawtucket Falls. Moody was released from his contract with the Boston Manufacturing Company and signed a new agreement to set up and run a large shop on a site at the junction of the Pawtucket and Merrimack Canals. By the spring of 1824, his machine shop was supplying machinery for the second and third Merrimack mills. It soon became the principal supplier for all the early mills of Lowell. (9)

Moody estimated that the Pawtucket Canal could provide power for sixty mills the size of the second one built at Waltham. In time, his analysis would prove too conservative, but first the system of branch canals had to be completed. By 1825, the planners had laid out routes for four more power canals. (10) Three were to branch from the Pawtucket Canal: two at the Swamp Locks Basin and one near the Concord River. The fourth canal would be an offshoot of the Merrimack Canal. The system would have two levels, with only the Merrimack Mills using the full thirty-foot head of the falls. Other mills on the upper level would use only thirteen feet of head. Water would exit from their wheel pits into a lower-level canal to provide a seventeen foot drop for mills along the river banks.

The Pawtucket Canal was back in operation as a transportation channel in 1824. Boott had rebuilt its Guard Locks with a lock chamber for transport and a set of sluice gates to control the flow into the system (and thus the elevation of water in the upper level). The

Guard Locks held back high water in floods and formed the entrance to the controlled canal system. A dam and two lock chambers at the Swamp Locks dropped the water level thirteen feet into the lower Pawtucket Canal; a similar arrangement at the Lower Locks created the final seventeen foot drop to the Concord River. Boott had reconstructed all the lock chambers with stone retaining walls and wooden linings. Although the Pawtucket Canal still had an irregular shape in many places, Boott had tried to create a sixty-by eight foot rectangular cross-section above the Swamp Locks Basin.

The canal system was not yet very large or complex, but already the problems of managing construction projects, textile mills, and a new machine shop were becoming troublesome for the directors of the Merrimack Manufacturing Company. By 1825, they had begun arrangements to transfer the machine shop, most of their land, and the control of the canal system to the Proprietors of Locks and Canals, the same corporation they had taken over in 1822. (11) Now there would be one company which would sell land and rent water power to new corporations. The Merrimack Manufacturing Company would be just one of many mill complexes on the canal system, all dependent on the power supplied by Locks and Canals. Of course, stock subscriptions gave the owners of the original manufacturing company a chance to share in the profits of the canal company. Boott served as the agent of both companies, despite the obvious conflict of interest.

From 1825 to 1836, the engineers and construction crews of Locks and Canals worked to complete the planned canal system. They dug an upper level canal leaving the Swamp Locks Basin and running parallel to the lower Pawtucket. The Hamilton Manufacturing Company built their mills on the strip of land between these canals, in a miniature version of the ideal power plan described above. Water from the Hamilton Canal dropped into the breast wheels in each mill and discharged thirteen feet below into the lower level canal.

The Hamilton Manufacturing Company was the first corporation to lease water power in units called "mill powers". One mill power represented the amount of power used to drive the machinery in the second mill at Waltham, about sixty net horsepower. The flow rate of the water which will produce a mill power varies with the height



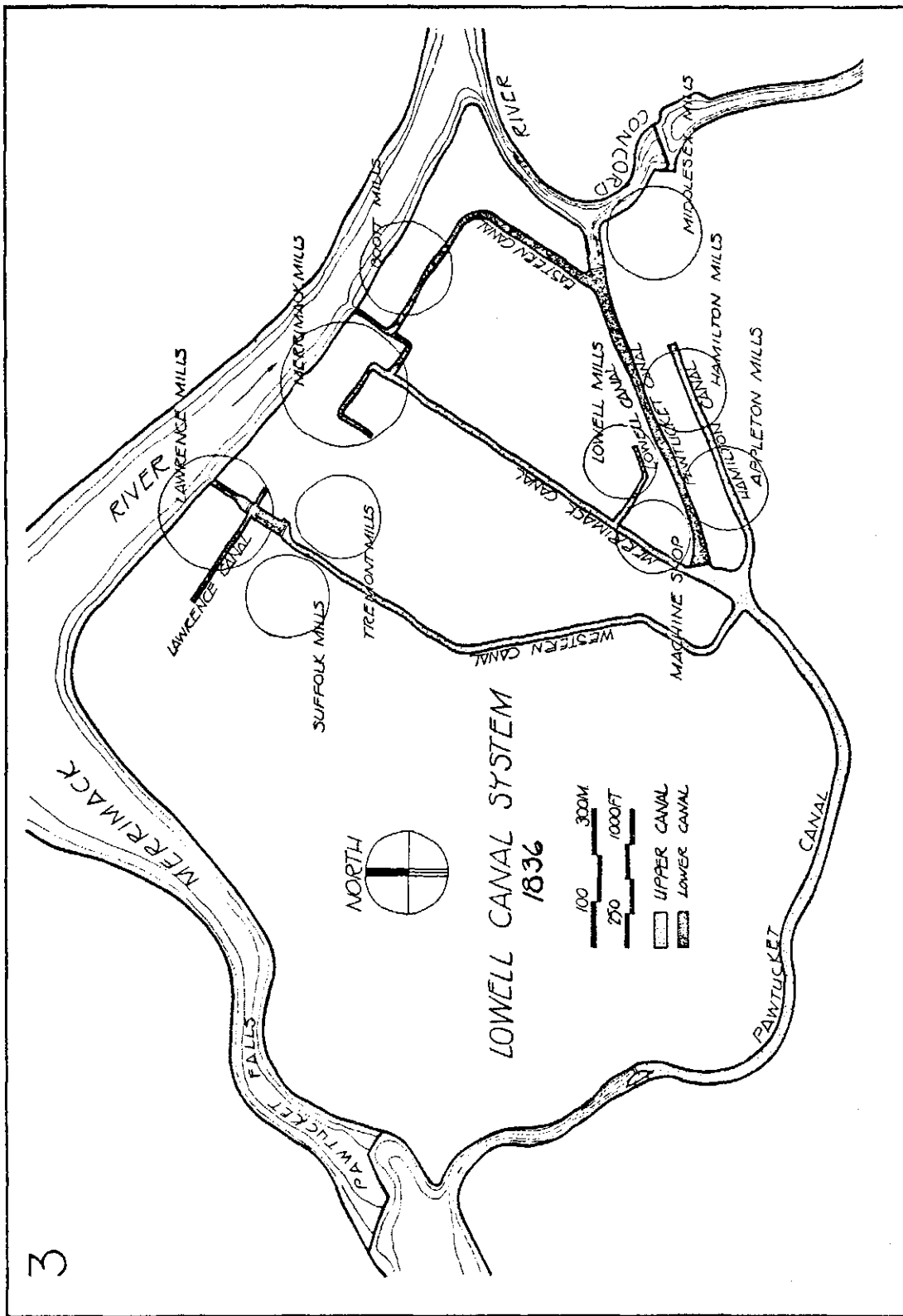
of the fall. With a thirty foot fall, one mill power requires a flow rate of twenty-five cubic feet per second. With a thirteen foot fall (between upper and lower levels on the Locks and Canals system) this becomes 60.5 cubic feet per second, and with a seventeen foot fall (from the lower level back to the river) the quantity is 45.5 cubic feet per second. Corporations could and did purchase more than one mill power for a single factory. (12)

When the carefully-planned canal system was completed in 1836, twenty-six textile mills, two print works and the machine shops of Locks and Canals were operating with power supplied by the Merrimack River. The nine mill complexes on the system produced 49,413,000 yards of cloth that year and employed almost 8000 workers out of a total population of 17,600. (13) Within the city, canals and the mills they powered were the dominant features of the urban landscape. Corporate housing, small businesses, and private homes were built only where they did not interfere with the routing of power canals and the production of textiles. The first priority in the development of Lowell was to bring water power to the best mill sites.

The Lowell Canal, built in 1828, was little more than an extended headrace off the Merrimack Canal. It entered the millyard of the Lowell Manufacturing Company, the first company in the world to use power looms successfully for weaving carpets. The carpet mills and the machine shop of the Proprietors of Locks and Canals were on land between the upper-level Merrimack Canal and the lower Pawtucket. Both corporations used this thirteen-foot difference in water level to power their mills. They took only a small part of the water moving in the Merrimack Canal; the rest continued down that channel to the extensive complex of the original manufacturing corporation.

The Western canal, like the Pawtucket, had both an upper and a lower level. Opened in 1831, it soon provided power for three corporations. First, the flow was split to supply the Tremont and Suffolk Mills on either side of the upper level. Tailraces from these mills then emptied into the lower level leading to the Lawrence Mills. Thus, the water was already used once for power generation before it reached the seventeen-foot wheels of the mills along the river.

The lower level of the Pawtucket Canal carried water discharged



by the machine shop and the Hamilton, Appleton, and Lowell Mills. A small part of this flow entered the Middlesex Mills, the only woolen manufacturer on the system and the only corporation to use water from both the Merrimack and Concord rivers. The main flow went into the Eastern Canal, which was opened in 1836 to supply the Boott Mills. In 1839, the Massachusetts Mills also bought land on the Eastern and began to build the last of the great mill complexes in Lowell.

Since 1826, the engineers of Locks and Canals had been able to increase the flow into the canal system by constructing dams at Pawtucket Falls. The first was a crude wooden structure, but by 1830, a masonry dam seated on heavy wooden cribbing was helping to maintain a "pond" behind the falls. Three years later, workmen added two more courses of granite headers and raised wooden flashboards above them. This not only raised the level of the upper river but also slowed its current for over eighteen miles. (14) The new dam, however, could not satisfy the water needs of the growing industrial city for long.

The demand for water power increased each year in Lowell as corporations expanded their manufacturing operations. Power was always scarce in the dry summer months, but by the 1840's, shortages were common throughout the year. One problem was the severe friction losses in the canals created by greater flow rates. When mills needed more water, the current had to increase to meet this demand. Increased current produced friction which actually dropped the level of water in the canals, reducing its potential to generate power. Thus, the mills could only get a greater flow of water by giving up some of the "head" they also needed. In times of freshet, river water rose into the tailraces of mills on the lower level of the canal system, impeding their wheels. Such "backwater" conditions placed excessive demands on the canal system, for only a tremendous flow of water could keep wheels turning in flooded wheel pits.

James B. Francis, the British-born chief engineer of Locks and Canals in this period, wanted to build a second feeder canal to bring additional water into the system and to allow a reduction of current in most of the canals. In order to make such a plan effective, however, two conditions had to be met. First, Locks and Canals would

have to prohibit the use of water for manufacturing at night, so that the river's flow could be "ponded" until the morning. Second, the power company would have to control the outlets of the major lakes which fed the Merrimack River. Using the lakes as reservoirs, Lowell would then have a source of extra water in dry seasons.

Before this new canal plan was approved, the ownership of Locks and Canals changed, and the chief engineer also became the company's agent. In 1845, the directors of the corporation sold the machine shop and a large amount of land. Next, they drew in all the stock, paying a fair price to each shareholder. New stock was issued to corporations on the canal system in direct proportion to the amount of water power each leased. (15) The users became the owners, and Locks and Canals became a service company for ten textile corporations and an independent machine shop.

Thirty-one mills containing 228,858 spindles and 6304 looms were on the canal system by the end of 1845. These factories, together with the Lowell Machine Shop and the two print works, put a tremendous strain on the outdated waterways of Locks and Canals. Adding to the problem, many corporations planned to expand their manufacturing capability in the immediate future. One large mill was in construction for the Hamilton Manufacturing Company and three other companies had decided to build additional factories. The owners of the machine shop were advertising that they could erect and furnish an average mill of 6000 spindles in just three months. (16) New mill space could also be provided at minimal cost by linking two existing mills with a central pavilion, thus forming one extended industrial structure. Any form of expansion, however, would produce increased demands for power.

Recognizing the urgent need for the new feeder canal recommended by Francis, the treasurers of the water-powered corporations gave their assent to the larger of two canal designs in 1846. The chief engineer had prepared both designs after gaining an agreement on nightly ponding and on the purchase of reservoirs. In combination with the Essex Company of Lawrence, Locks and Canals had acquired control of over one hundred square miles of lake surface in New Hampshire. (17) Now, Francis could begin work on the greatest

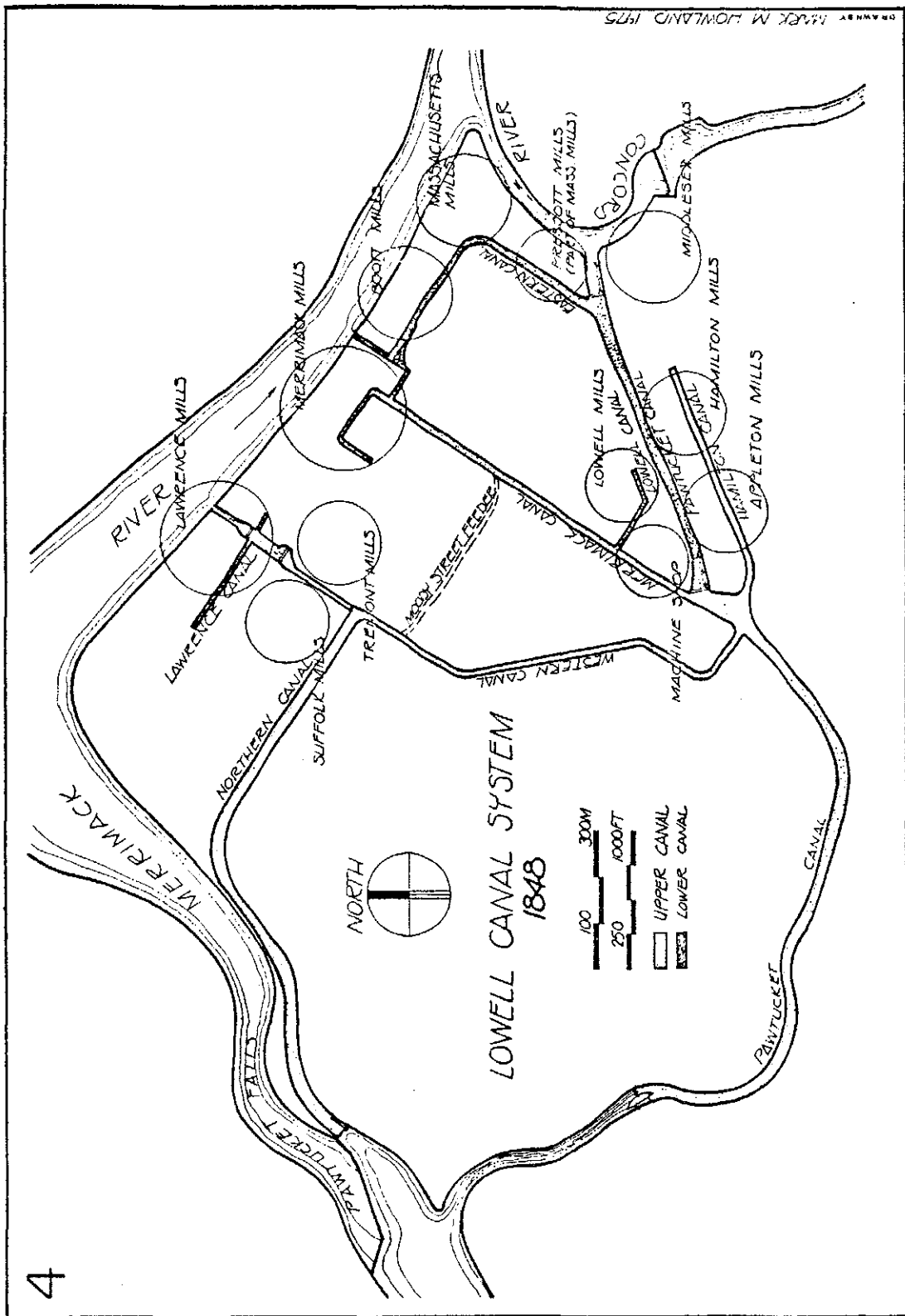
engineering challenge of his career, the Northern Canal.

Between 1846 and 1848, Francis supervised the construction of the Northern Canal, the Pawtucket Gatehouse at its entrance, and two underground waterways tying together parts of the canal system. He also directed the rebuilding of a section of the Pawtucket Dam in order to channel water into the gatehouse of the new canal. Over a thousand men were on the payroll at one time, and hundreds of others worked for firms providing contracted services and materials.

The completed Northern Canal ran for 4,400 feet from the head of the Pawtucket Falls to the Western Canal. The first 1000 feet cut across an outcropping of land, but the next 1000 feet of the canal was built beside the river, some of it on ledges that had been underwater when the project began. The final section turned inland to complete the linkup with the existing canal system. With at least fifteen feet of water in its one-hundred-foot-wide rectangular channel, the Northern Canal could carry a greater flow than the Pawtucket while keeping friction losses to a minimum.

The part of this grand canal which extended into the natural bed of the river was the most impressive sight on the canal system. Here, the "Great River Wall" held the water of the canal above the lower rapids of Pawtucket Falls and formed an elevated walk for the enjoyment of the public. The massive wall of coursed granite was lined with rubble laid in cement and was founded upon ledge. In some places its vertical height above the ledge reached thirty-six feet. (18) Near the downstream end of the exposed wall, the chief engineer installed four manually-operated waste gates, two scouring gates, and an overflow weir.

Ten sluice gates at the entrance to the canal controlled the water admitted from the upper river. Housed in a brick gatehouse with a foundation of granite masonry, these gates were operated with water power. Francis used his own version of the Howd inward-flow turbine to drive a line shaft in the gatehouse. Belts and pulleys connected this shaft to the gate-hoisting machinery. Also housed in the building were large testing chambers and other apparatus used by Francis in a series of Scientific experiments which became part of his famous work, Lowell Hydraulic Experiments. (19)



The Northern Canal brought water into the system with a higher head than previously had been possible, and it reversed the current in the Western Canal from the junction to the Swamp Locks Basin. Water from the Northern supplied the demands of the Tremont, Suffolk, and Lawrence Mills. Once Francis had completed the Moody Street Feeder in 1848, the Northern also fed the Merrimack Canal through three brick-vaulted tunnels. A smaller underground passage, known as the Boott Penstock, transferred some of this flow from the Merrimack Canal to the end of the Eastern Canal, where an adequate water level had always been hard to maintain.

Locks and Canals spent \$551,585 on the Northern Canal and \$86,132 on the Moody Street Feeder. The Boott Penstock and the necessary widening of the Western Canal added another \$15,000 of expenses. (20) Yet, the power gained by the various Lowell corporations was easily worth the cost. The construction program dramatically reduced the current in most of the canals and increased the head on both the upper and lower levels by one to two feet. Each leased mill power was therefore worth more in terms of gross horsepower. After testing the results of his physical improvements to the system, Francis arranged for a redistribution of power and an increase in the number of mill powers leased to each company. Because of the limitations of the old Pawtucket Canal as the sole feeder, only ninety-one mill powers had been leased up to that time. The Northern Canal enabled the chief engineer to lease 139 mill powers. These were so-called "permanent" mill powers to be supplied in all seasons; for most of the year, the corporations could also purchase "surplus" mill powers at an inexpensive rate. The mill complexes were assured of over nine thousand net horsepower, even in summer. (21)

Francis was far ahead of his time in his concern for the most efficient use of power. His studies of the various ways in which energy was wasted in both canals and factories led to many improvements. He was particularly critical of American machines for being "great consumers of power". American industrialists wanted a machine "to turn off the greatest quantity of work with the least manual labor, and in the least time." He thought they gave far less consideration to "whether it required a greater or less amount of power." (22) He

also evaluated systems of mechanical power transmission in mills, following the example set by Paul Moody at the Appleton Mills in 1828.

Moody rejected the heavy bevel gears and vertical iron shafts which had been used in other Lowell mills to transmit power from the basement to line shafts on upper floors; they were difficult to manufacture and wasted energy because of excessive friction. Instead, he used huge leather belts and pulleys to carry power up to the horizontal shafting in the Appleton Mills. Although belts of this type were already known in England, they were soon much more common in America. Some observers even considered them a distinctive feature of the American factory system in the 1840's. With later improvements in metal shafting and prime movers, belt-driven mills could achieve faster operating speeds and greater production for the amount of energy consumed. (23)

Acting as "Chief of Police of Water", Francis tried to prevent all unnecessary waste on the system and developed techniques to monitor the water used by individual corporations. When the flow in the river was low, he even closed the entry gates on the Northern Canal during the noon break. (24) His test of Uriah Boyden's outward-flow turbines in 1844 and 1846 convinced him that corporations should switch from breast wheels to more efficient turbines. In this way, they could produce more net horsepower from each mill power delivered to their sites. Under perfect conditions, two Boyden wheels had reached a tested efficiency of eighty-eight per cent, and average efficiencies in the range of seventy-five per cent could be expected. Also, turbines, which ran well underwater, could generate during "back-water" conditions that ruined the performance of breast wheels. (25) The widespread conversion to turbines in Lowell took place during and immediately following the construction of the Northern Canal.

The chief engineer's experimental work resulted in an improved inward-flow turbine and in effective methods for measuring rates of flow in open channels and over weirs of various shapes. Like the chemist Samuel Dana at the Merrimack Print Works, Francis was highly successful in the use of scientific methods for the benefit of industry. He made the canal system a laboratory for hydraulic experi-

ments; and here at Lowell, perhaps for the first time in America, science exerted a regular and profound influence on technology.

The city was in many ways a professional school for civil and mechanical engineers. Uriah Boyden, who once worked for Locks and Canals, trained Ezekiah Straw, a Lowell High School graduate and later the chief engineer and agent of the giant Amoskeag Company in Manchester, N.H. Asa Swain, like Boyden an important figure in the development of hydraulic turbines, began his professional career as a pattern-maker in the Lowell Machine Shop. Joseph Frizzell, Clemens Herschel, and Hiram Mills became famous hydraulic engineers after working for Francis on dam and canal projects. The mills and shops of Lowell provided opportunities for such machine designers as Moody, John Goulding, William Bement, Warren Colburn, Samuel Batchelder, and Erastus Bigelow. Countless lesser-known figures who learned their trade or sharpened their skills in Spindle City also made significant contributions to American technological progress.

The conversion of raw cotton into cloth was still the most mechanically-complex manufacturing process in the city at mid-century. Technological improvements had speeded production and raised quality, but the overall process had not changed dramatically since the opening of the first Merrimack Mill. Visitors to a cotton mill could follow the operations step-by-step, with the aid of the following published description:

From the storehouse, the cotton is distributed to the picker-houses, where it is opened, beaten up and cleaned, and from thence passes to the mill in the form of a light fleece, wrapped on cylinders called laps. It is in this form that the visitor first sees it in the card-room, where it is carded, doubled, and perhaps recarded, then again doubled, and drawn in the drawing frame, to be again and again drawn, and slightly twisted by the speeder and stretcher; it is now passed to the spinning room, in the form of a light loose card, called roving; in this room it is spun into yarn of two kinds, warp and filling, or weft, of which the first is the harder twisted. The machines used in spinning here, are usually throstles, but mules have been introduced lately, as being more economical in the power necessary to drive them. From the spinning-room, the warp is passed to the dressing-room, where it is warped or wound on beams, dressed (or sized with starch, the fine fibres brushed down and dried, so as to make a smooth, even thread), and the threads drawn into the harness, ready for the loom; it is now sent to the weaving room, where the filling has already arrived

from the spinning-room; the warp is on the beam, and forms the web; the filling is on bobbins, and is put in the shuttle. The product of the weaving-room is cloth; it is then sent to the cloth-room to be looked over, picked and measured; then sent to the print-works, or bleachery, or baled, and put on the cars for Boston. (26)

Industrial structures dominated the urban landscape of Lowell at mid-century. Many manufacturers had come to supply the needs of the great textile corporations for belts, shuttles, card clothing, rollers, and hundreds of other items. Companies with products unrelated to textiles located in the city because of its pool of skilled workers, its excellent transportation links to widespread markets, or its reputation as a clean and orderly industrial community with an unlimited future. The population had soared from 2500 in 1826 to over 33,000 in 1850. The rapid growth of the city was due primarily to its water power, but steam had also played a major role in industrial development and was becoming more important every year.

Steam locomotives and railroads made possible regular and rapid transportation between Lowell and other major cities. In 1832, Patrick Tracy Jackson imported two British locomotives for the Boston and Lowell Railroad he was constructing. Two years later, he hired George Whistler, a West Pointer and an experienced railroad engineer, to build engines on the British design in the machine shop of Locks and Canals. A Lowell-built locomotive, the Patrick, ran on the line when it opened in the summer of 1835, and the machine shop soon became a supplier for other railroads. By 1838, thirty-two locomotives made by Locks and Canals were in service in New England, New York, Pennsylvania, and Maryland. (27)

The Boston and Lowell Railroad, famous for its "Great Cut" in Lowell and for its six-arch, masonry bridge over the nearby Concord River, was only the first of many lines to enter the city. The Nashua and Lowell opened in 1838, the Lowell and Lawrence in 1847, and the Salem and Lowell in 1850. The growing competition from railroads caused the closing of the Middlesex Canal in 1852. Ironically, the canal had carried the first British locomotive to the city twenty years before, thus ushering in the era of the steam railroad in Massachusetts.

Steam was also important in the heating systems of Lowell mills,

in textile finishing processes such as bleaching and dying, and in the production of power at locations without an adequate, year-round source of water power. Sites for small-scale manufacturing using waterwheels or turbines were limited in Lowell. Only the great textile corporations could lease mill powers supplied by the Merrimack River; other companies seeking water power clustered around the two falls on the Concord River or used the minimal energy available at sites on several brooks. In times of drought, the owners of marginal water rights had to cease manufacturing unless they had also purchased a steam engine for supplemental or "stand-by" power.

Many early mills, because of their locations, must have been powered entirely by steam engines. Water power, particularly that provided by Locks and Canals, was usually less expensive than steam power, but the difference narrowed as railroads brought in steady supplies of coal and as George Corliss and others improved the efficiencies of engines. (28) Makers of such wooden products as shuttles, boxes, and bobbins could use the scraps from their manufacturing processes to feed their boilers for heat and power. Another cost-saving practice was to run steam through an engine first and then to use the exhaust to provide the steam required in the heated mill rooms or in some high-temperature manufacturing or finishing process. Steam power in these situations was sometimes a better choice than water power.

The Handbook for the Visiter to Lowell, printed in 1848, explained that steam "had been extensively introduced to drive saw-mills, planing machines, work-shops, and small manufactories; the tall chimneys rising in various parts of the city, inform the visiter of their location and number." At the large saw-mill of Fiske and Norcross, "the refuse, bark, sawdust and shavings, is employed to drive the works." The Lowell Bleachery, incorporated in 1832 and built on River Meadow Brook, was also "driven by steam"; and at the Lowell Manufacturing Company, steam had recently been installed "for boiling and power, in addition to their water power." (29)

The Merrimack Print Works used so much of the water power leased to the Merrimack Manufacturing Company that the directors of the corporation made a massive switch to steam power for their finishing processes. This allowed them to expand their water-powered textile

manufacturing while Francis was finishing the Northern Canal. Production increased from an average of 253,000 yards of cloth per week in 1846 to 345,000 yards per week in 1847. The reorganized, steam-driven print works made effective use of exhaust steam for processing and also expanded its capacity to match the greater flow of cloth from the company's mills. In 1865, the corporation had twenty-one steam engines with a total of 1,210 horsepower. (30) Apparently, all these engines were at the print works.

Seven of the ten textile corporations on the canal system had installed some steam power by the end of the Civil War. (31) Very little cotton textile production had taken place in Lowell during the war, but manufacture increased steadily thereafter. Most of the power for expansion on the system could no longer be provided by the Merrimack River. Although Francis did increase the effective head for mills along the river bank by dredging the channel and lowering a falls downstream, he could not change the annual flow in the Merrimack. Only one hundred and thirty-nine "permanent" mill powers were ever leased.

The following table shows the industrial expansion on the canal system in terms of spindles and steam power. Water power can be considered a constant figure of approximately 10,000 net horsepower.

ANNUAL STATISTICS - TEN TEXTILE CORPORATIONS (32)

	SPINDLES	STEAM ENGINES	STEAM HORSEPOWER
1865	437,420	29	2885
1870	499,746	30	3690
1875	692,888	67	7733
1880	703,670	88	11,950

The Statistics of Lowell Manufactures for 1875 and 1880 show the total number of steam engines and their aggregate horsepower for all the prominent manufacturers in the city. In 1875, the compilers listed 69 engines and 8,783 horsepower. Five years later steam power had passed water power, not only in the city as a whole but also on the canal system of Locks and Canals. The statistical summary for 1880 included 119 engines producing 16,157 H.P. As shown in the table above, the ten largest textile corporations had 88 of these engines

and 11,950 of the total horsepower.

There was no sudden transition in Lowell from an "Age of Water Power" to an "Age of Steam Power". Steam simply became the most important prime mover for industrial expansion after all the available water power was already in use. Water turbines continued to supply inexpensive power, and water rights were as jealously held as ever. The great corporations built steam mills near their operating water-powered mills or formed hybrid factories using both power sources. Many other companies erected their plants beside the rail lines leading into the city, creating patterns of linear development similar to those along the rivers and canals.

In 1880, the economy of Lowell was still dominated by textile and textile-related manufacturing. Although the city also had its makers of ammunition, paper, carriages, cabinets, knives, patent medicines, and other varied products, textiles were the city's raison d'etre. The number of spindles had grown to 770,662, and the number of looms to 19,648. The Lawrence Manufacturing Company also had 500 knitting machines turning out hosiery, undershirts and "drawers." Purchasers of Lowell's machinery and other textile-related products included not just local mills but also companies all over the country. The Kitson Machine Shop, for example, was rapidly becoming one of the nation's largest suppliers of specialized textile machines for opening, lapping and picking. (33)

Lowell's continuing growth was impressive, but the city was losing ground to other rising industrial centers. It was no longer even the largest cotton textile producer in Massachusetts; by 1875, Fall River could claim that title. (34) More serious, perhaps, than the loss of its pacesetter position among manufacturing cities was the decline of Lowell's reputation as a paternalistic, even utopian, industrial community. Immigrant workers had replaced most of the "Yankee mill girls," and boarding houses were being sold by corporations which no longer needed such inducements to attract a work force. Exploitation of labor for increased production and profit was becoming a standard practice in the mills.

In engineering as in textile manufacture, Lowell had begun to slip from the limelight by 1880. The Lowell Machine Shop had become

dependent on other companies for innovations in machine design, and the Holyoke Testing Flume in Western Massachusetts had taken over the evaluation of turbine performance. James B. Francis was still a giant in his profession, but, after working on the dam and on several systems of gate control in the 1870's, he faced no further significant challenges on the network of canals. The old chief engineer was the principal link with the glorious days of engineering achievement in Lowell. Engineers all over the world continued to seek his advice and to read his publications on hydraulics, fire prevention, cast iron columns, and other technical subjects.

The historic engineering and industrial structures in Lowell today reflect the technical skill which created them. Lowell's engineers, technicians, and workers have left us a lasting heritage in the man-made environment of their city. They harnessed the Merrimack River and the power of expanding steam, built the sturdy factories, and connected the city to distant markets and sources of supply. A modern period of industrial decline and economic depression has not diminished the accomplishments of Lowell's early years. The first great American industrial city was not only a leader in textile production but also a showpiece of engineering expertise.

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